(5) 779 3-

(9) PROGRESS ~~REPORT NO.~~ 6, 1 Feb - 31 Mar 61

ON

(6) STUDY OF THE VIBRATION CHARACTERISTICS

OF BEARINGS,

(7-8) NA

(10) by Ulrich Kinnett and Olaf Gustafson.

(11) 1 Mar 61,

Period February 1 to March 31, 1961

(12) IV,

(13) NA

(16 17) NA

(18.19) NA

(21) u

Submitted to:

U.S. DEPARTMENT OF THE NAVY

CHIEF, BUREAU OF SHIPS

WASHINGTON 25, D.C.

Reported		U.S. Navy (15) Contract [redacted]	NObs-78552
Supervised	(14)	U.S. Navy Index No.	NE 071 200
Approved		[redacted] Rep[redacted]t,no.	AL61L014
		SKF Code	61021270 - 61021253
		SKF Project	V-3
		SKF Reg.	585 14 : 422 3

(21) NA

RESEARCH LABORATORY

SKF INDUSTRIES, INC.

PHILADELPHIA, PA.

PROGRESS REPORT NO. 6 - NAVY CONTRACT NObs-78552

SUMMARY

1. Airborne noise and structure borne vibrations of 6310 size bearings were investigated on the bearing vibration tester for bearings with 25 to 100 mm bore. The relationships between amplitude and speed and between airborne noise and structure borne vibrations are shown.

2. Structure borne vibrations and airborne noise measured in absolute units, (microinches/second velocity and absolute acoustical decibels) of 6305 and 6310 size bearings are compared.

3. The effect of housing mass on bearing frequencies is displayed.

4. A discussion of the results is given.

5. The state of progress in the manufacture of the large bearing vibration tester is described.

6. Plans of work for the immediate future are given.

DETAILS

1. Tests on 6310 Bearings

In continuation of the studies of the effect of load and rotational speed on vibrational amplitude, ten 6310 bearings were tested in the same manner as the 6305 bearings reported in Progress Reports 4 and 5. Since the load carrying capacity of 6310 size bearings is higher, higher loads were applied in order to maintain a similar order of specific loading (50, 100, 200, 300, 400 and 500 lbs. radial load and approximately 60 lbs. axial load). The same speeds (1000, 1800, 2500, 3000, 3600 rpm) as for the 6305 bearings were maintained.

The test bearings were mounted in cylindrical housings 6.5" diameter by 1.25" wide with a push fit, looseness 0 to .0015", between bearing O.D. and housing. The support bearings were also 6310 bearings, mounted in pillow blocks with the same fit as the test bearings. The structure borne vibrations of the test bearings, in direction of and normal to the radial load were measured. The airborne noise generated by the two test bearings and two support bearings combined was measured in absolute acoustical decibels.

The same normalizing procedure was applied as used for the 6305 size bearing measurements. This is recapitulated as follows: the average of the one vibration reading each in the 200-400, 400-800 and 800-1600 bands for five radial loads between 100 and 500 lbs. and at 1800 rpm was computed for each bearing. The amplitude ratio was then obtained by dividing every individual reading taken on a given bearing by the average level computed for the same bearing. Then the amplitude ratios of the ten test bearings for identical test conditions (speed, load, octave band, direction of vibration) were averaged and plotted.

The instrumentation used in measuring the structure borne vibration and airborne noise was recalibrated after the tests on the 6310 bearing since it was planned to report absolute readings in more detail. There is reason to believe that this calibration is more accurate than the calibration used as the basis of measurement on the 6305 bearings (reported as normalized values). All data given in this report are based on the new calibration.

Enclosures 1 to 8 show the effect of load and speed on the vibrational amplitude ratio for individual octave bands (average of ten 6310 bearings) for the direction normal to the load and Enclosures 9 to 16 represent the same relationship for the vibration in direction of the load. The speed/amplitude exponents α in the relation $V = Kn^{\alpha}$ were determined by plotting the curves of Enclosures 1 to 16 on logarithmic paper (plots are not enclosed as they contain no new information). The exponent α for the individual octave bands is plotted in Enclosure 17.

The airborne noise results were normalized in a similar way as the structure borne vibrations. An average reading (in db)was subtracted from all individual noise readings and then the average of the five test assemblies was formed. Average normalized airborne noise measurements for 6 loads and 5 speeds are plotted in Enclosures 18 to 25. In order to compare the speed/amplitude relationship of airborne noise and structure borne vibrations, the latter ones were converted to decibels (normalized amplitude ratio 1 = 0 db) and also plotted in Enclosures 18 to 25.

2. Amplitudes of Structure Borne Vibrations and Airborne Noise in Absolute Units

In the tests reported in Progress Reports 4 and 5, emphasis was placed on the effect of load, speed and other parameters on the vibrational amplitude; and only relative amplitudes were reported. To compare the vibration levels of the 6305 and 6310 bearings measured, the vibration levels of these bearings were also determined in absolute units. Since the load dependence was found to be rather small and erratic, the absolute vibration level is not given for the various loads used in the tests. Only the vibration levels in the different frequency bands, averaged over the loads used, are given.

Enclosures 26 to 34 are graphs showing the amplitude of structure borne vibrations in absolute units of velocity (microinches/second) in eight octave bands averaged over the loads used. 6305 size bearings are shown in Enclosures 26 to 29 and 6310 size bearings in Enclosures 30 to 34. In Enclosures 27 and 31 (at 1800 rpm), the corresponding amplitudes obtained on the standard SKF vibration tester (without radial load and only light thrust load) are also shown, with the bearings mounted in the same housing as used in the tests under radial load. Octave bands of the airborne noise in absolute acoustical decibels of 6305 and 6310 size bearings are plotted in Enclosures 35 and 36.

The ambient noise level in the anechoic chamber was determined for each measurement taken. Noise levels in identical frequency bands, from two independent sources, are additive by squares

$$V^2 = V_1^2 - V_2^2 \qquad (1)$$

where V = noise of bearing alone (in linear units)

V_1 = ambient noise and bearing noise together (in linear units)

V_2 = ambient noise (in linear units)

If the vibration levels are expressed in decibels rather than linear units, the noise generated by the bearings alone becomes:

$$D = D_2 + 10 \log_{10} \left(10^{\frac{D_1 - D_2}{10}} - 1\right) \qquad (2)$$

where D_1 = ambient noise and bearing noise together (in db)

D_2 = ambient noise (in db)

D = noise of bearings alone (in db)

The noise levels reported in Enclosures 35 and 36 were determined using Equation (2). At low frequencies the effect of the ambient noise is appreciable and at high frequencies its effect is negligible. The ambient noise was found to be the same without as with the disconnected drive motor (outside the chamber) operating at any speed. In interpreting the airborne noise level it should be noted that the noise stems from two test and two support bearings together. If it is assumed that airborne noise from the 4 bearings is additive by squares and that each individual bearing generates the same noise (these are approximations at best due to interactions and differences in housing shape of test and support bearings), the noise level of one bearing should be 6 db smaller than the level reported.

In order to show the effect of bearing size on the vibration level, absolute amplitudes of structure borne vibration and airborne noise of 6310 size bearings were compared to those of 6305 size bearings. The ratios between the levels of 6310 and 6305 bearings are tabulated in Enclosure 37. This comparison of levels is of little generality because no care was exercised to compare bearings of identical quality.

3. Effect of Mass on the Vibration Spectrum

In order to gain more information on the parameters affecting the vibration spectra of different size bearings, tests on the standard SKF test spindle (under light thrust load and no radial load) were carried out with 6205, 6305 and 6310 size bearings with different masses (housings) surrounding the outer ring. Similar cylindrical housings as in the tests under radial load, with a push fit, (0 to .0015" looseness between bearing O.D. and housing, were used. In Enclosure 38, octave band analyses are shown of structure borne vibrations of 6205 bearings with four different housings. (The average of four bearings is given). Enclosure 39 shows average octave band vibration spectra of ten 6305 bearings with and without housing, and Enclosure 40 of the average spectra of ten 6310 bearings.

4. Discussion of Results

a. From Enclosures 1 to 17 it can be concluded that the effect of rotational speed on the vibration level of 6310 size bearings approximately follows a power function $V = Kn^{\alpha}$, with the exponent α larger than unity, as in the case of 6305 bearings. The exponent α is slightly smaller in all bands than for 6305 size bearings, but the difference does not appear to be significant. It is seen from Enclosure 17a that the curve representing α as a function of frequency for 6310 bearings is of similar shape as the corresponding curve for 6305 bearings (shown in Enclosure 17b) with somewhat higher α in the low and high frequency range than in the medium frequency range. The readings of the 6310 size bearings scatter more than those of the 6305 size bearings; an unexplained inconsistency of the amplitudes at 2500 rpm was observed in several frequency bands (Enclosures 1, 2, 5, 9, 11 and 12).

b. The effect of the magnitude of the radial load on the structure borne vibrations in case of 6310 size bearings is as small as for 6305 size bearings. In most frequency bands, there appears to be a tendency for the vibration level to increase with load. In some bands (1600-3200 and 3200-6400 cps bands for both directions of observation and 50-100 and 100-200 cps band in the direction of the load) the effect of load is highly erratic. Progress Report No. 4 showed that the vibration level of 6305 bearings appears to decrease with frequency in the 200-800 cps range. No such tendency was observed for 6310 bearings.

The variation between vibration levels for different loads is approximately the same for 6310 bearings as for 6305 bearings. It is mostly within 50% and does not exceed 100%.

c. The airborne noise increases with rotational speed with a similar trend as the structure borne vibrations, in all frequency bands above 200 cps, i.e. the correlation between airborne noise and structure borne vibrations is as good for 6310 bearings as it was found to be for 6305 bearings. The airborne noise measurements below 200 cps are practically meaningless, because they are too heavily over-shadowed by the ambient noise in the anechoic room. (An overhaul of the soundproofing of this room is planned for the summer 1961).

d. The effect of the magnitude of the radial load on the airborne noise level is as small as (or even smaller than) the effect on the structure borne vibrations. The noise level seems to increase with load in the whole frequency range above 200 cps. This was also observed for the 6305 bearings reported in Progress Report No. 5.

e. The spectral distribution of the structure borne vibrations of the 6310 bearings in direction normal to the load shows high amplitudes in the low frequencies and decreases gradually with increasing frequency, while the vibrations in the direction of the load are low at low frequencies, higher in the 400 to 3200 cps range and very low in the three highest octave bands. The spectra of the 6305 bearings shown in Progress Report No. 4 appear to follow approximately the same pattern, although some differences are found between the two bearing sizes. The airborne noise spectrum (Enclosures 35 and 36) does not show such a pronounced decrease in the high frequency range. The spectral distribution of the airborne noise compared to the structure borne vibrations indicates relatively higher absolute noise amplitudes in the three highest bands (1600-12800 cps) (Enclosures 23, 24, 25). The same effect was observed for the 6305 size bearings reported in Progress Report No. 5.

f. It was mentioned in Progress Report No. 4 that a housing is believed to detune the vibrations, reducing them especially in the high frequency range.

This effect can be illustrated by considering the bearing an ideal, single degree-of-freedom, vibratory system with an inertia element (mass), spring compliance and damping. The frequency response of this system is:

$$\frac{|\lambda|}{\delta_{st}} = \frac{1}{\sqrt{(k - m\omega^2)^2 + c^2\omega^2}} \qquad (3)$$

where k = spring constant

m = mass

ω = angular frequency

c = damping constant

$|\lambda|$ = displacement amplitude

$\delta_{st} = \frac{F_o}{k}$ = deflection under a static force equal to imposed harmonic force amplitude

Equation (3) shows the well known fact that increased mass decreases the amplitude at high frequencies more than at low frequencies by moving the resonant frequency downward. Although a bearing is not a system with a single degree of freedom but vibrates as a composite of several elastic bodies, it is seen from Enclosures 38, 39 and 40 showing the vibration of bearings tested with housings of various masses, that the added mass of the housing reduces the vibration level in the high frequency range. The effect of the housing is substantial. In some bands the bearing with the housing has a vibration level of only 10 or 20% of that obtained without a housing. Since the results are so highly influenced by the housings a comparison between the results on 6310 and 6305 bearings cannot directly be used to establish the correlation between vibration level and bearing size, when tested under radial load on the "Navy" tester. The size dependence of the vibration level when tested under axial load on the standard SKF tester can, however, be determined, if one uses bearings of the same smooth running quality (manufacturing refinement) in different sizes. The bearings used for the work reported herein were not selected to assure this and therefore no valid comparison is possible. A comparison of readings (Table D and E in Enclosure 37) is therefore given for the sake of completeness only.

Table A of Enclosure 37 shows the ratio between the vibration levels of 6310 and 6305 bearings tested under radial load, in the direction normal to the load with the bearings mounted in housings. Table B shows the same ratio in the direction of the radial load and Table G shows the ratio between the vibration levels of the same bearings mounted in the same housings, and tested under axial load on the standard SKF tester. A comparison of Tables A, B and G shows that the size dependence of the vibration level is not the same for radially loaded bearings as for thrust loaded bearings. A comparison between Tables A and B shows that the size dependence of the two vibration components is somewhat different. In the 200-800 cps range, the component in the direction of the load increases more rapidly with size than the other component. In the 800-6400 cps range, the component perpendicular to the load appears to increase faster than the component in the direction of the load. As in the case of 6305 bearings, the component in the direction of the load is smaller in general for 6310 bearings than the component in the direction of the load, the only exception being the 200-400 cps band, where the vibration level in the direction of the load is about 15% larger than in the direction normal to the load.

5. Large Bearing Vibration Tester

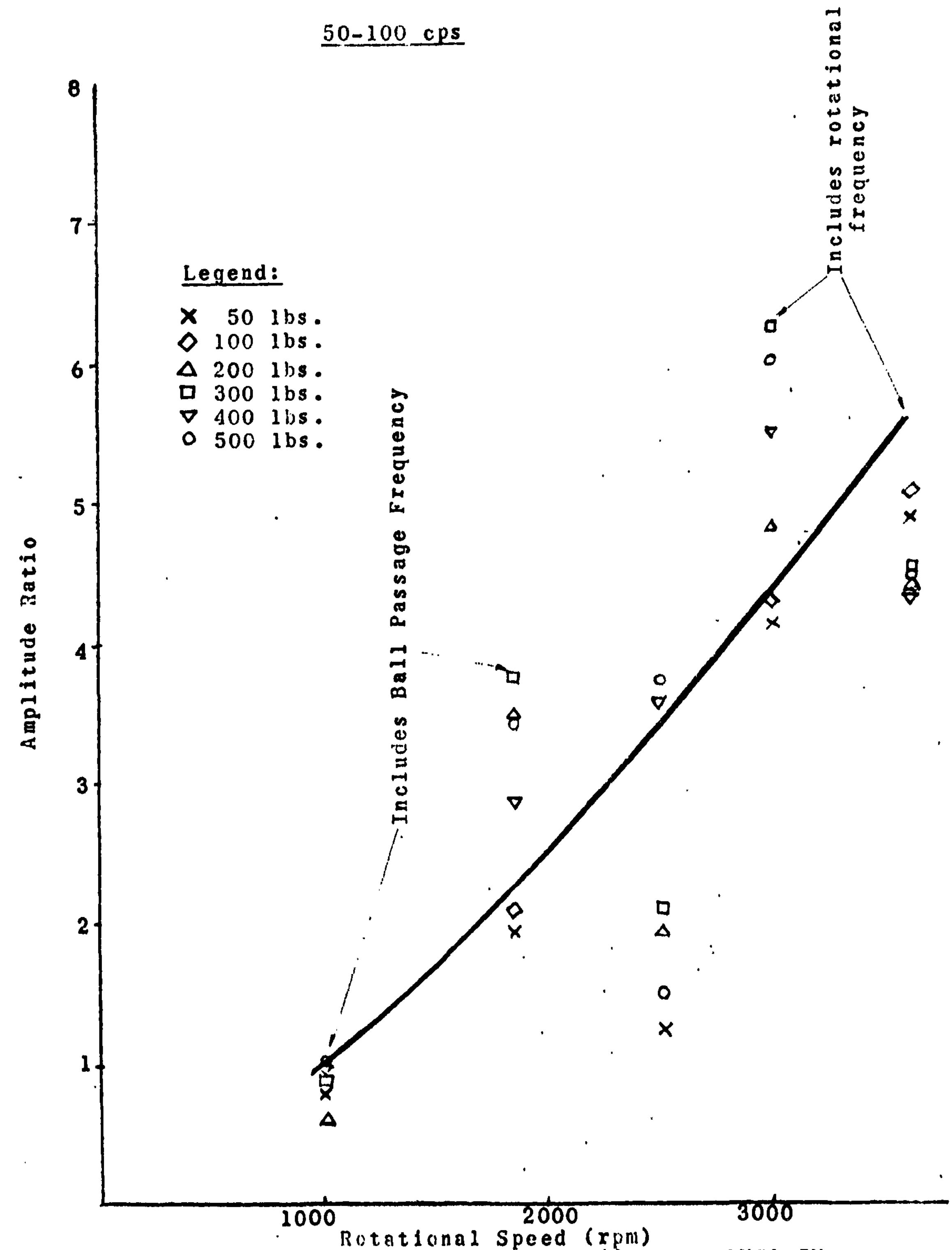
The Hydrostatic Journal and Thrust Bearings (Kingsbury Machine Works) and the Main Shaft (Midvale Heppenstall Company) were finished and sent to the Kutztown Foundry Company for alignment with the machine bed. The remaining parts of the Drive Unit were received and are being assembled. The high pressure and lubrication oil system was installed and the connections (electrical and hydraulic) to the main control panel are being made. This oil system consists of a 300 gallon reservoir, a 70 hp motor driving a Denison high pressure pump, filters and heat exchanger. It delivers up to 34 GPM high pressure (3500 psig) oil and up to 80 GPM low pressure (60 psig) lubrication oil. The hydrostatic lift in the journal bearings and thus the spring constant and damping can be varied by changing the high pressure oil flow. The hydraulic loading system, consisting of air driven pumps and hollow rams, was received. The strain indicator for the load control is at hand and will be calibrated to read directly in pounds of load.

6. Plans of Work for the Immediate Future

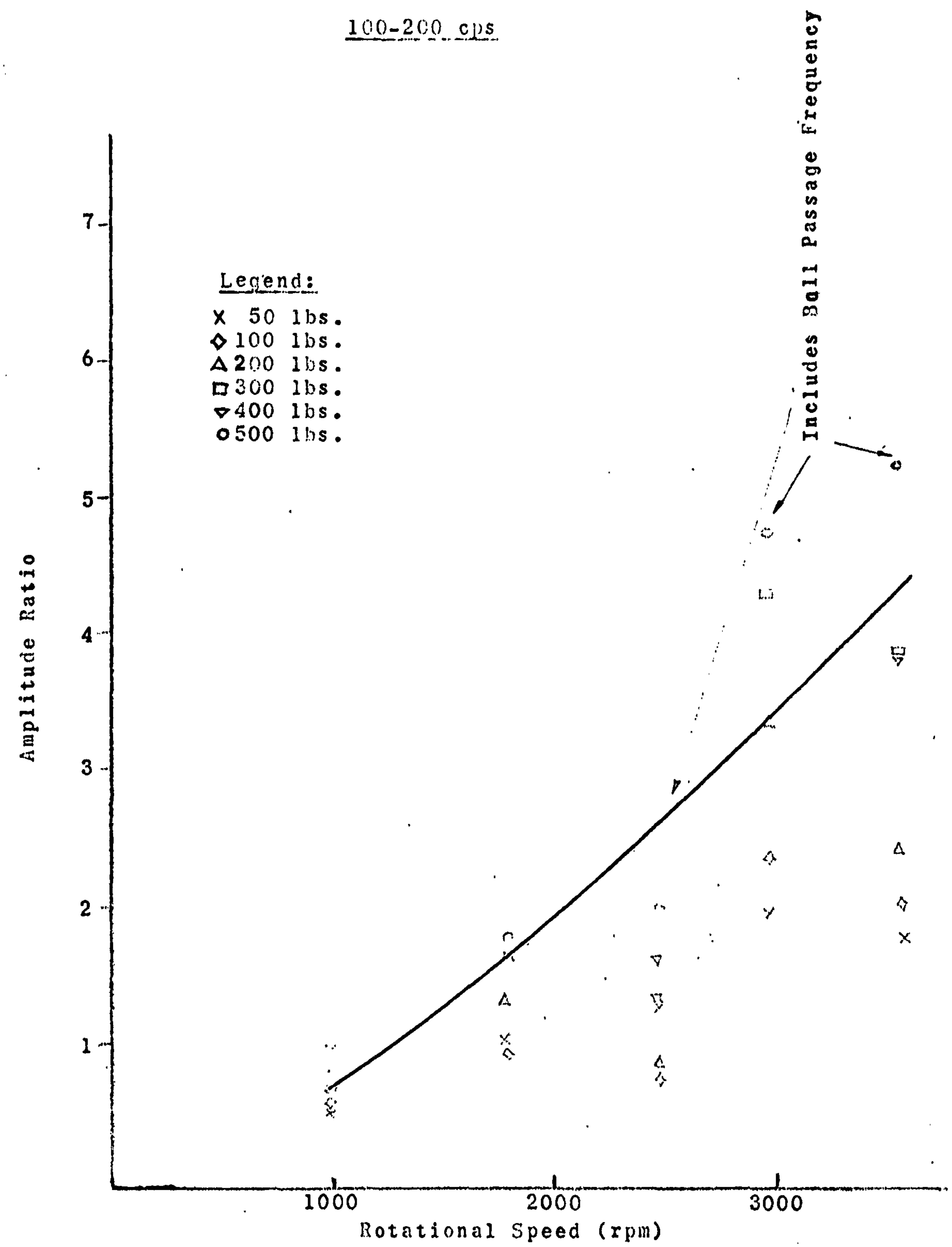
The vibrations induced by variable compliance will be studied by narrow band frequency analyses over the frequencies in question (ball passage frequency and multiples of it). The theoretically determined amplitudes for existing 6305 bearings (with known Hertzian coefficient, radial looseness and for the loads to be applied), will be verified experimentally. Support bearings with a different ball passage frequency will be used (6205 bearings).

The vibration transmission characteristics of ball bearings will be studied using a newly conceived tester.

Installation of the large bearing vibration tester will be completed and the tester will be tried out. The first bearing size to be tested is 23256 CAK.

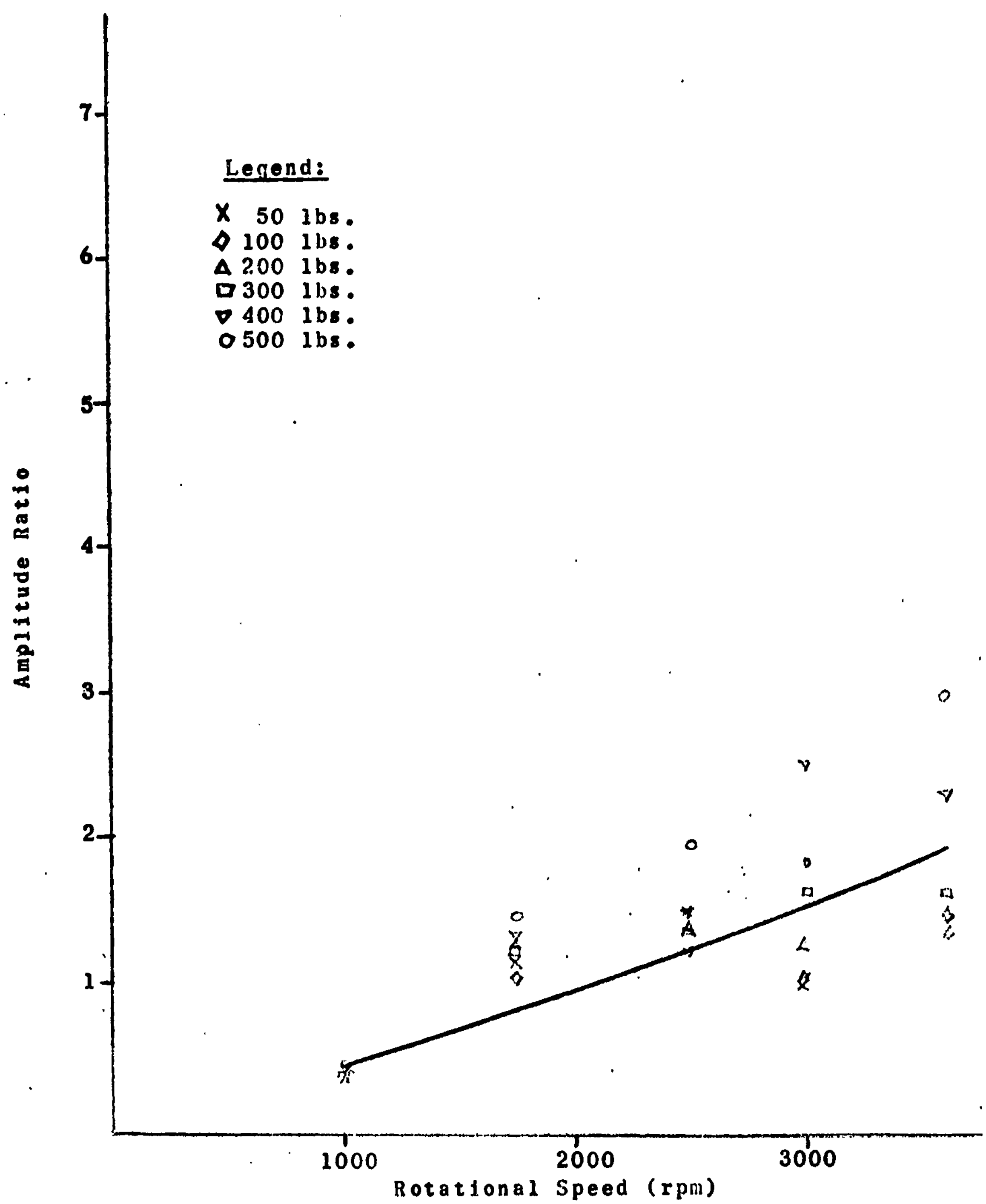


ENCLOSURE 1 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (50-100 cps FREQUENCY RANGE)

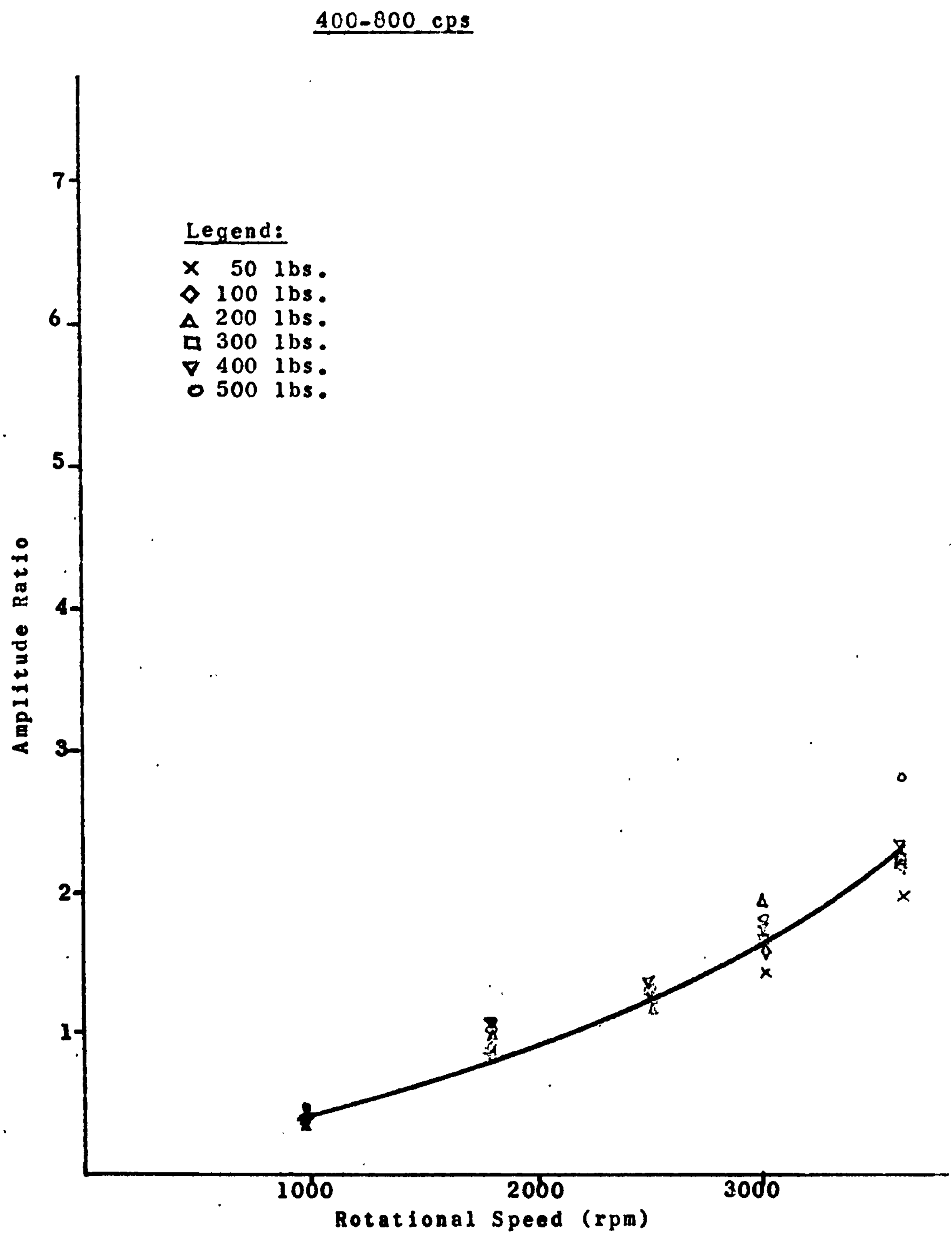


ENCLOSURE 2 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (100-200 cps FREQUENCY RANGE)

200-400 cps

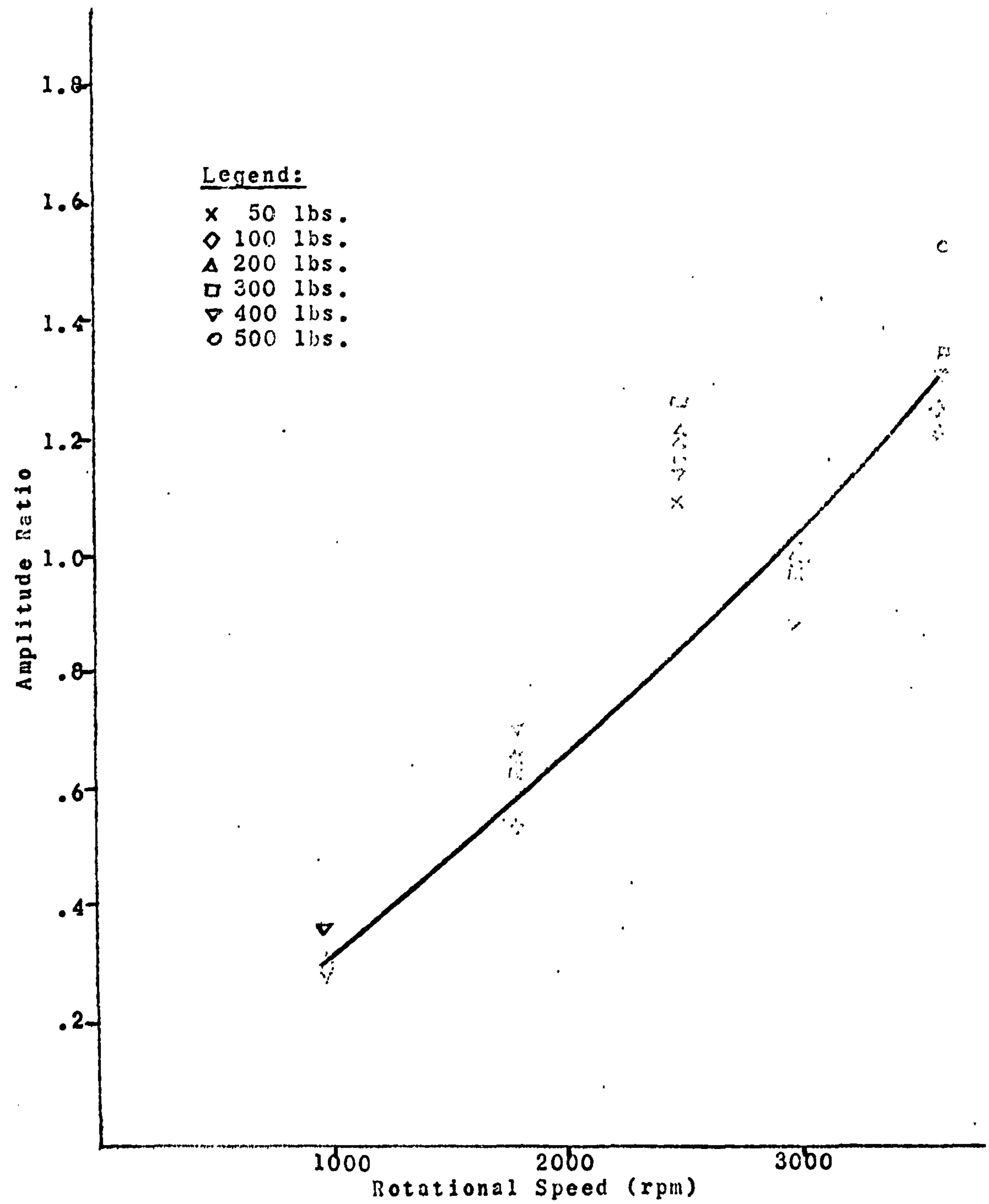


ENCLOSURE 3 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (200-400 cps FREQUENCY RANGE)

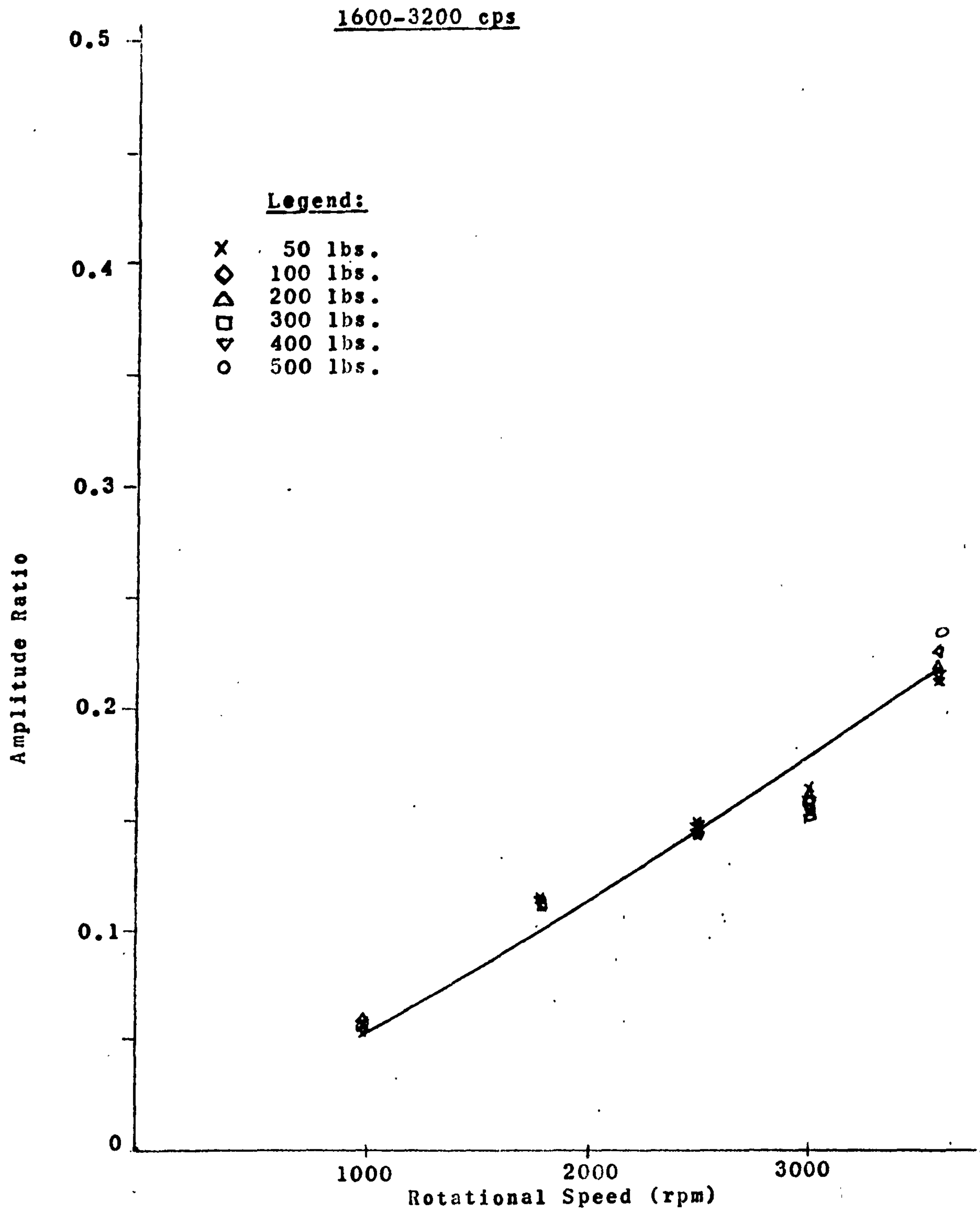


ENCLOSURE 4 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (400-800 cps FREQUENCY RANGE)

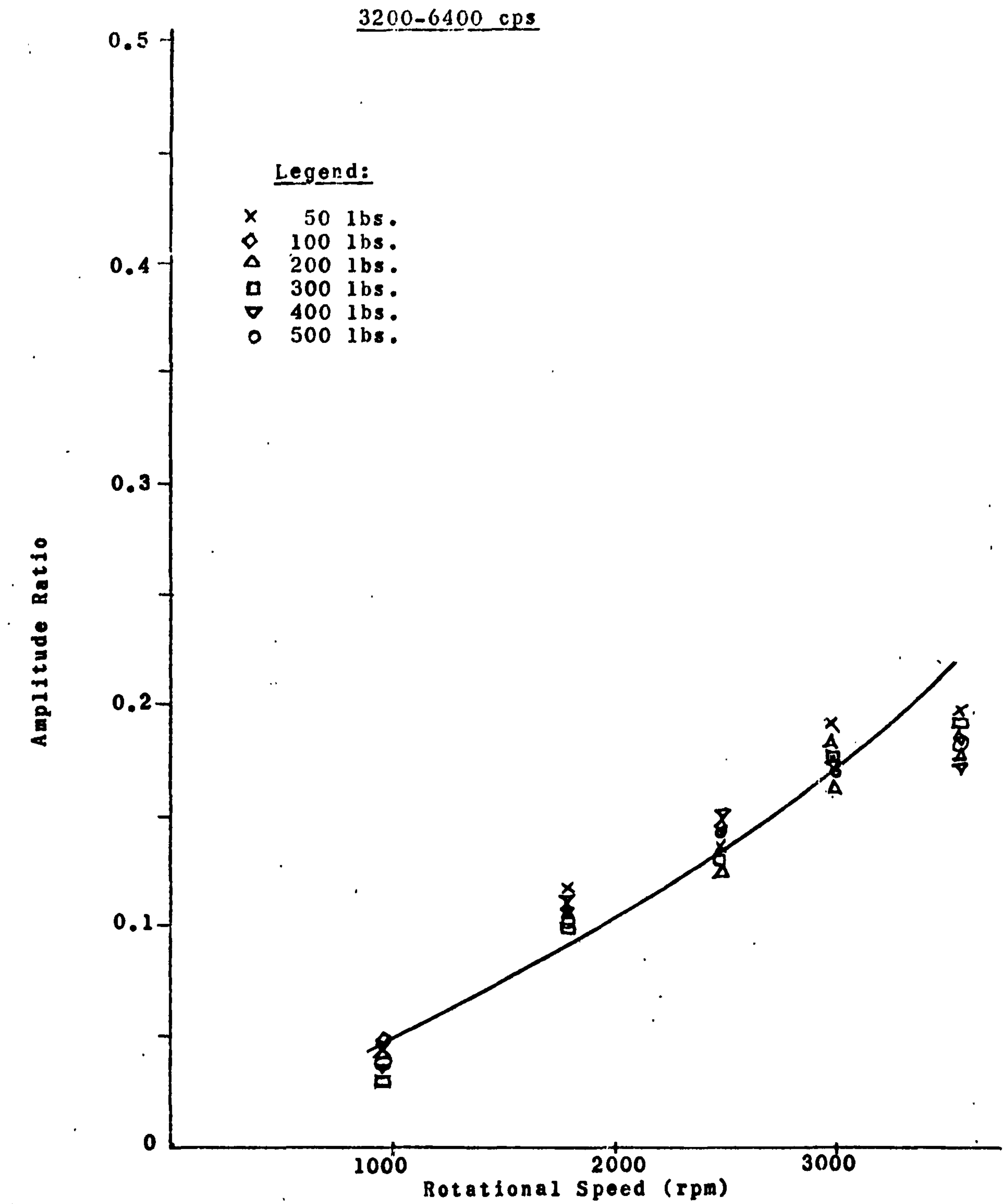
800-1600 cps



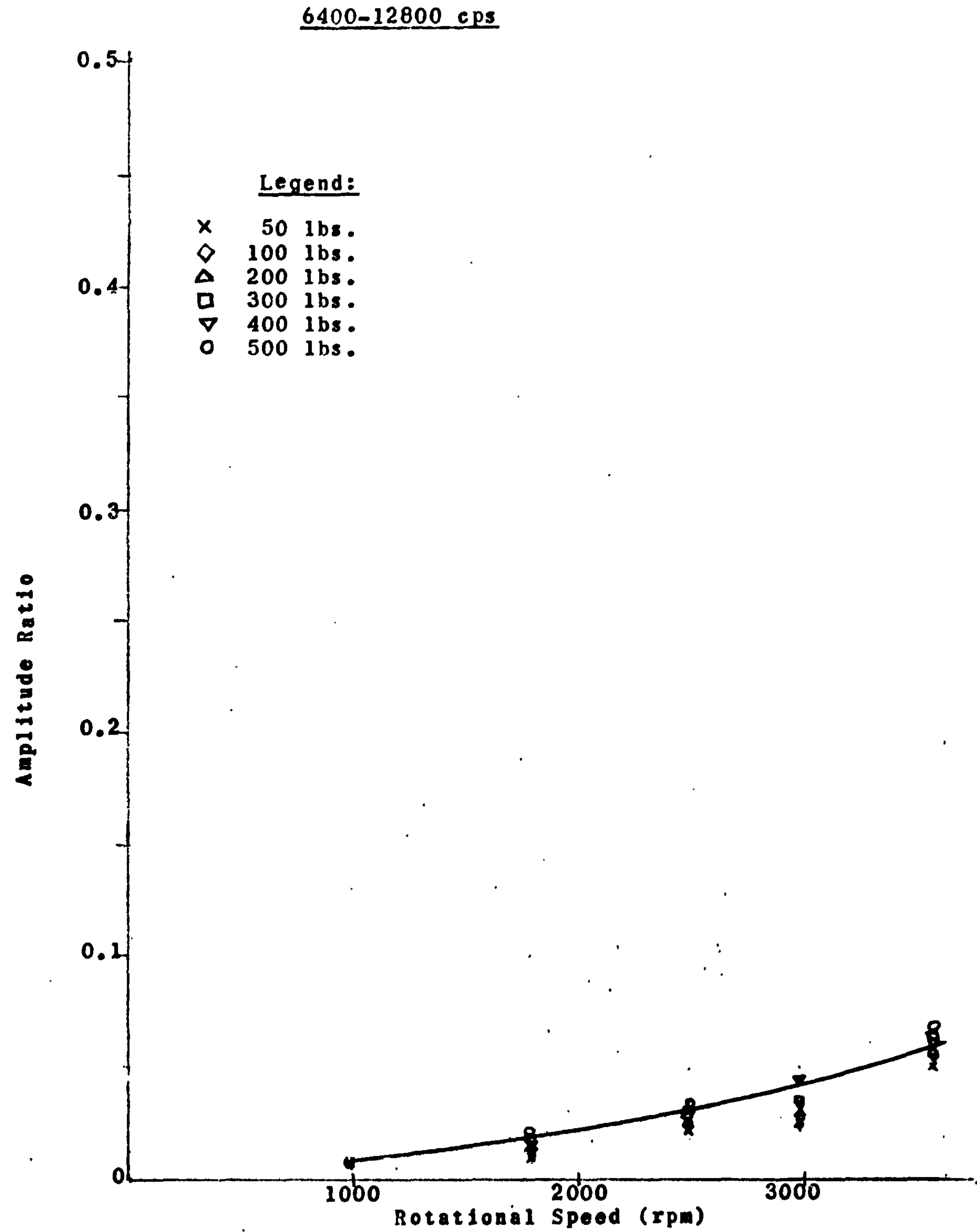
ENCLOSURE 5 STRUCTURE BORNE VIBRATION OF **6310** BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (800-1600 cps FREQUENCY RANGE)



ENCLOSURE 6 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (1600-3200 cps FREQUENCY RANGE)

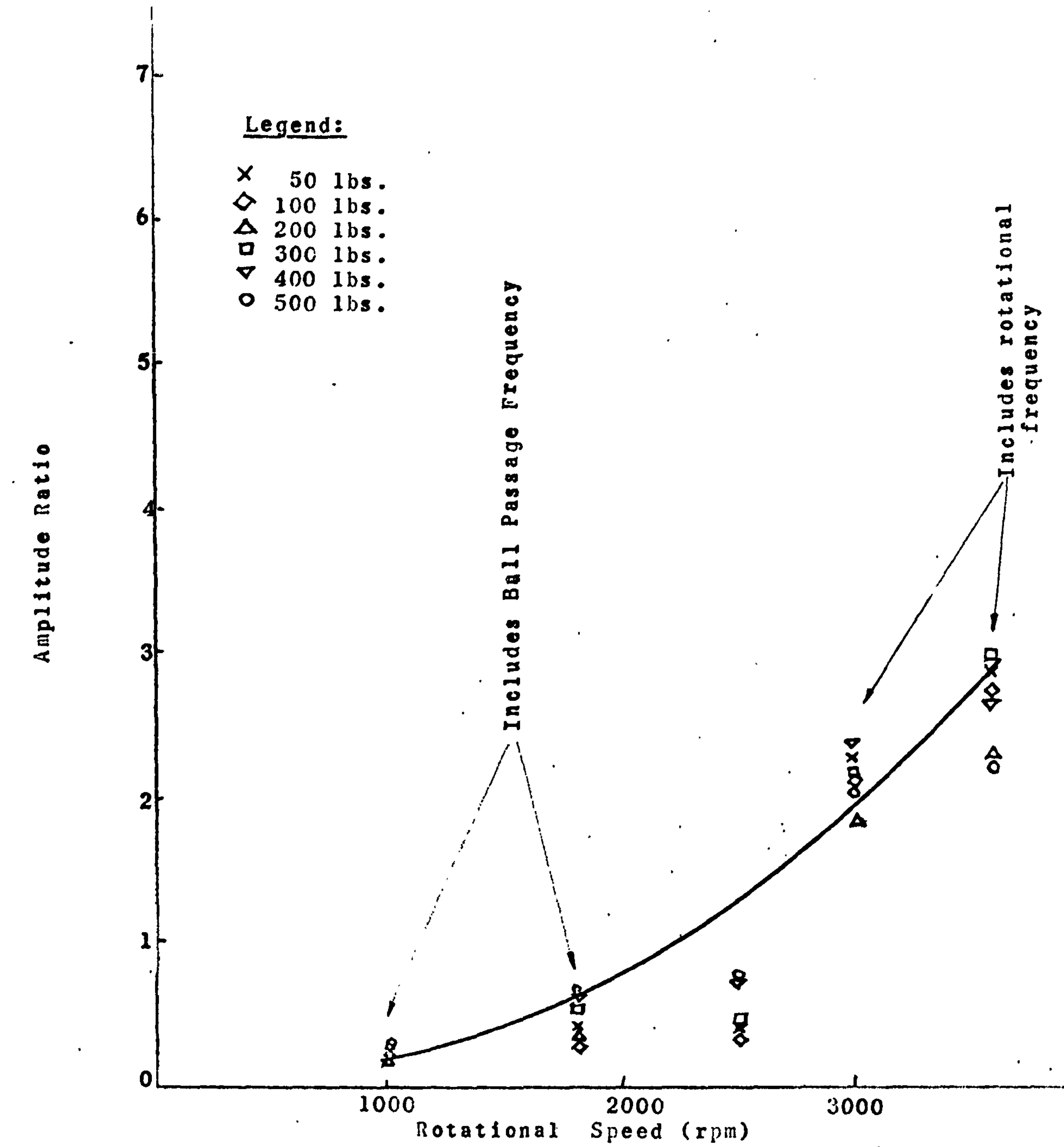


ENCLOSURE 7 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (3200-6400 cps FREQUENCY RANGE)

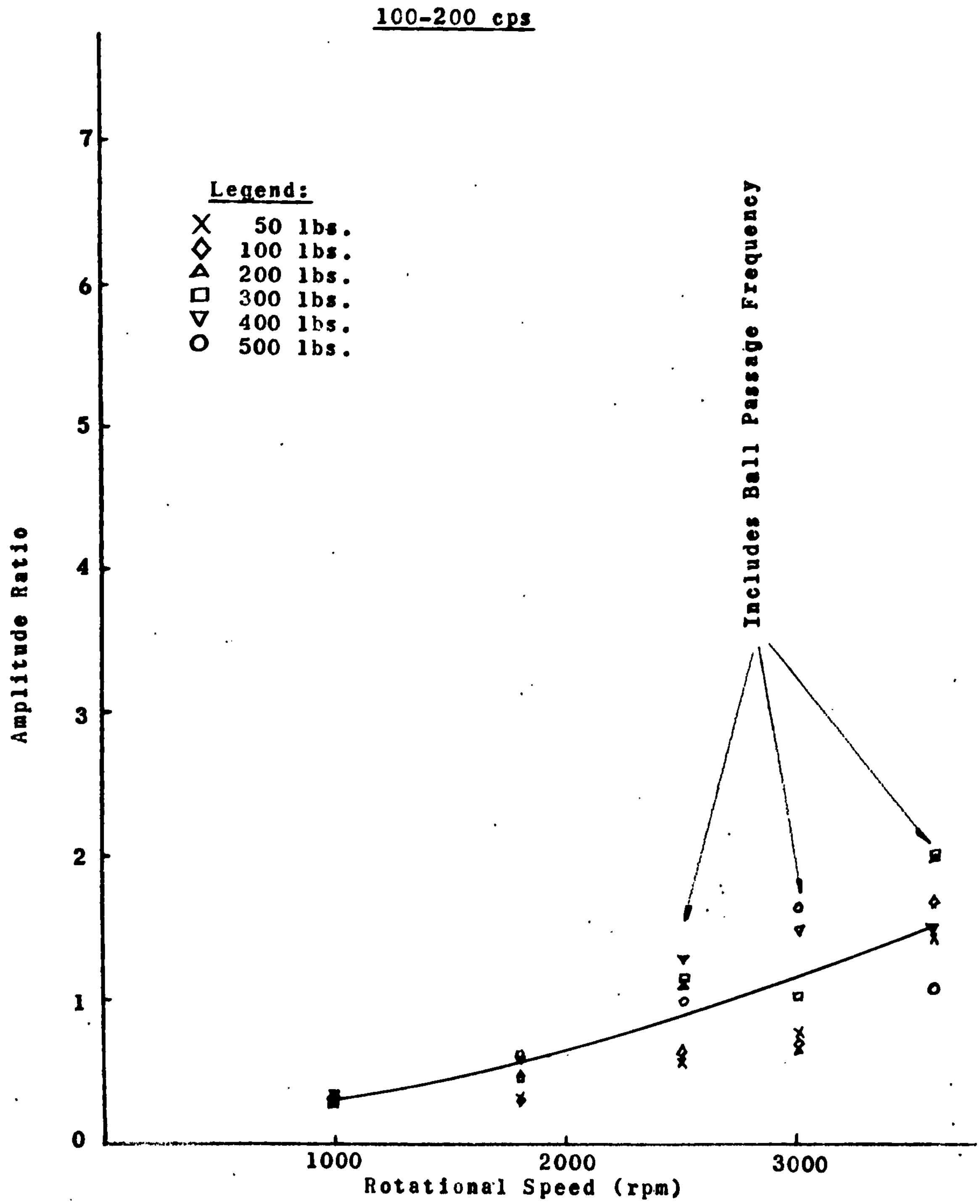


ENCLOSURE 8 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION NORMAL TO LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (6400-12800 cps FREQUENCY RANGE)

50-100 cps

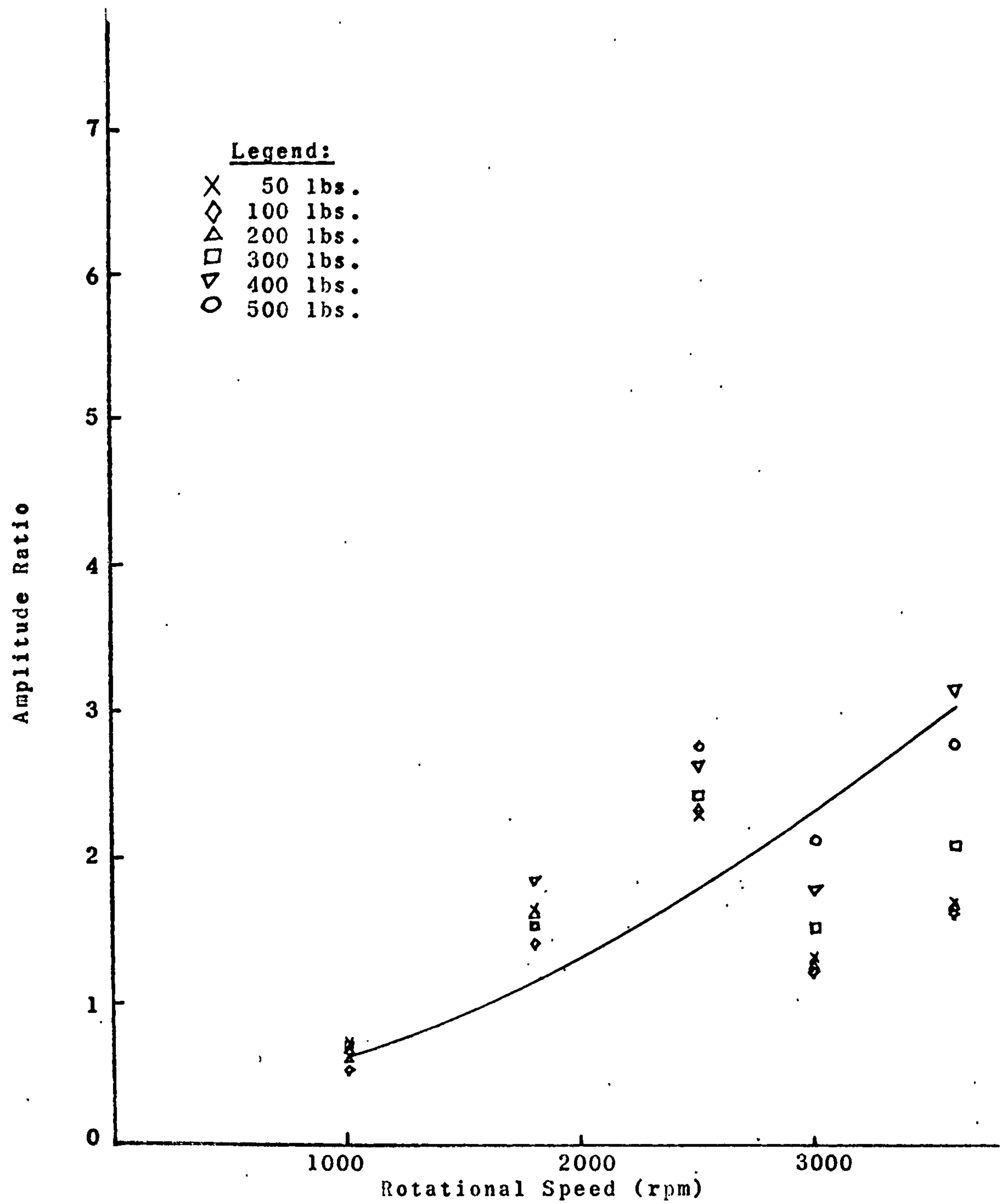


ENCLOSURE 9 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (50-100 cps FREQUENCY RANGE)

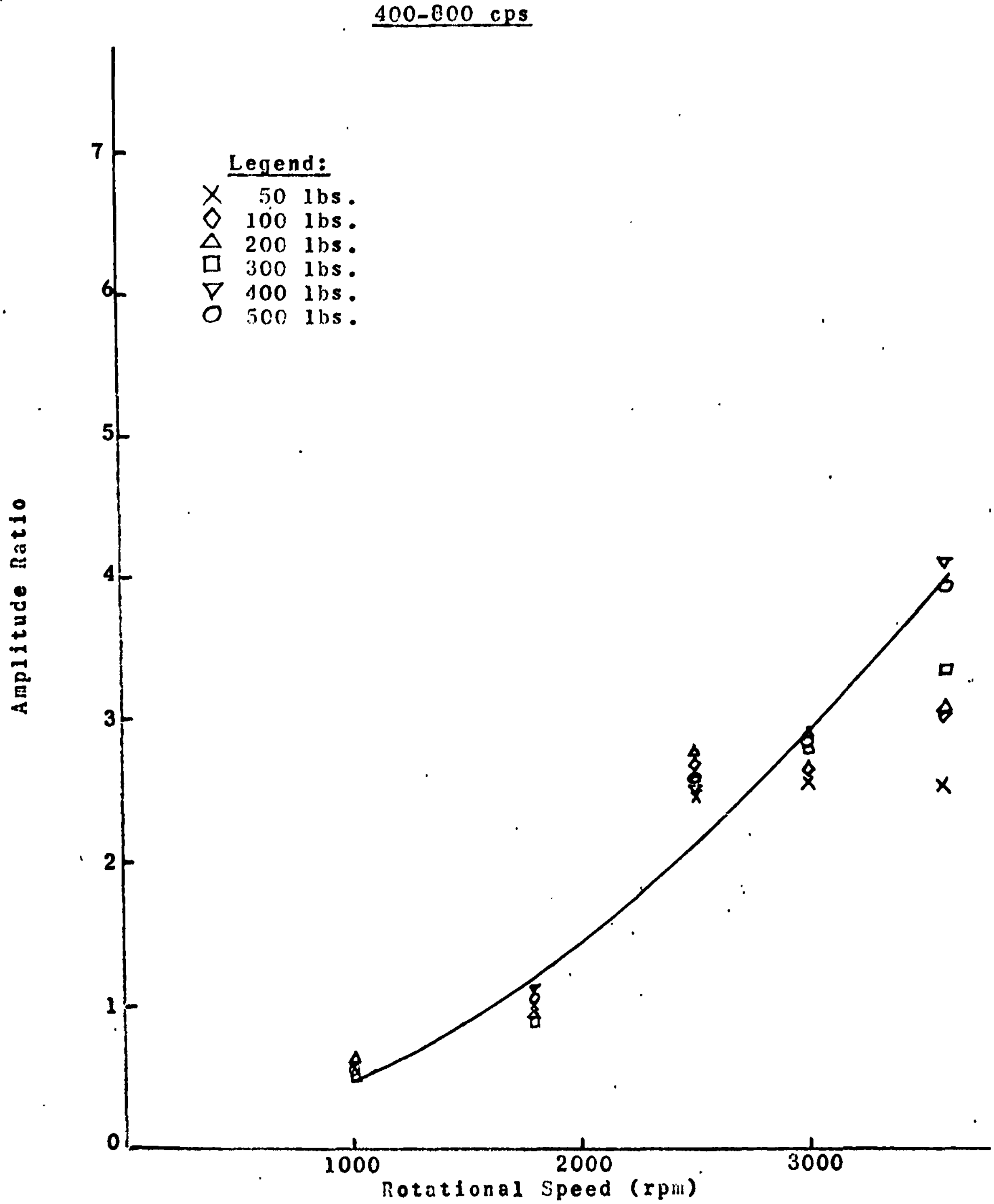


ENCLOSURE 10 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (100-200 cps FREQUENCY RANGE)

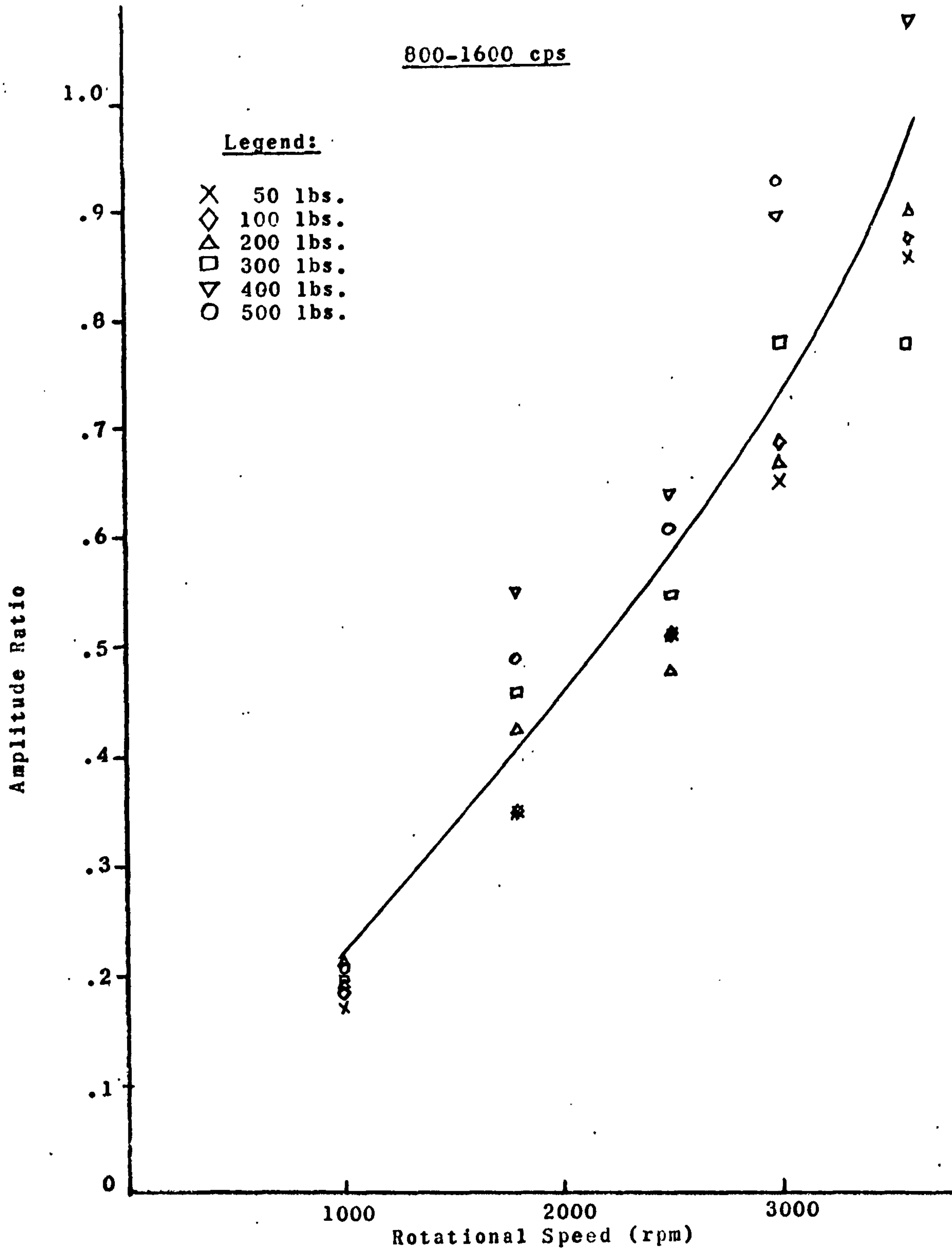
200-400 cps



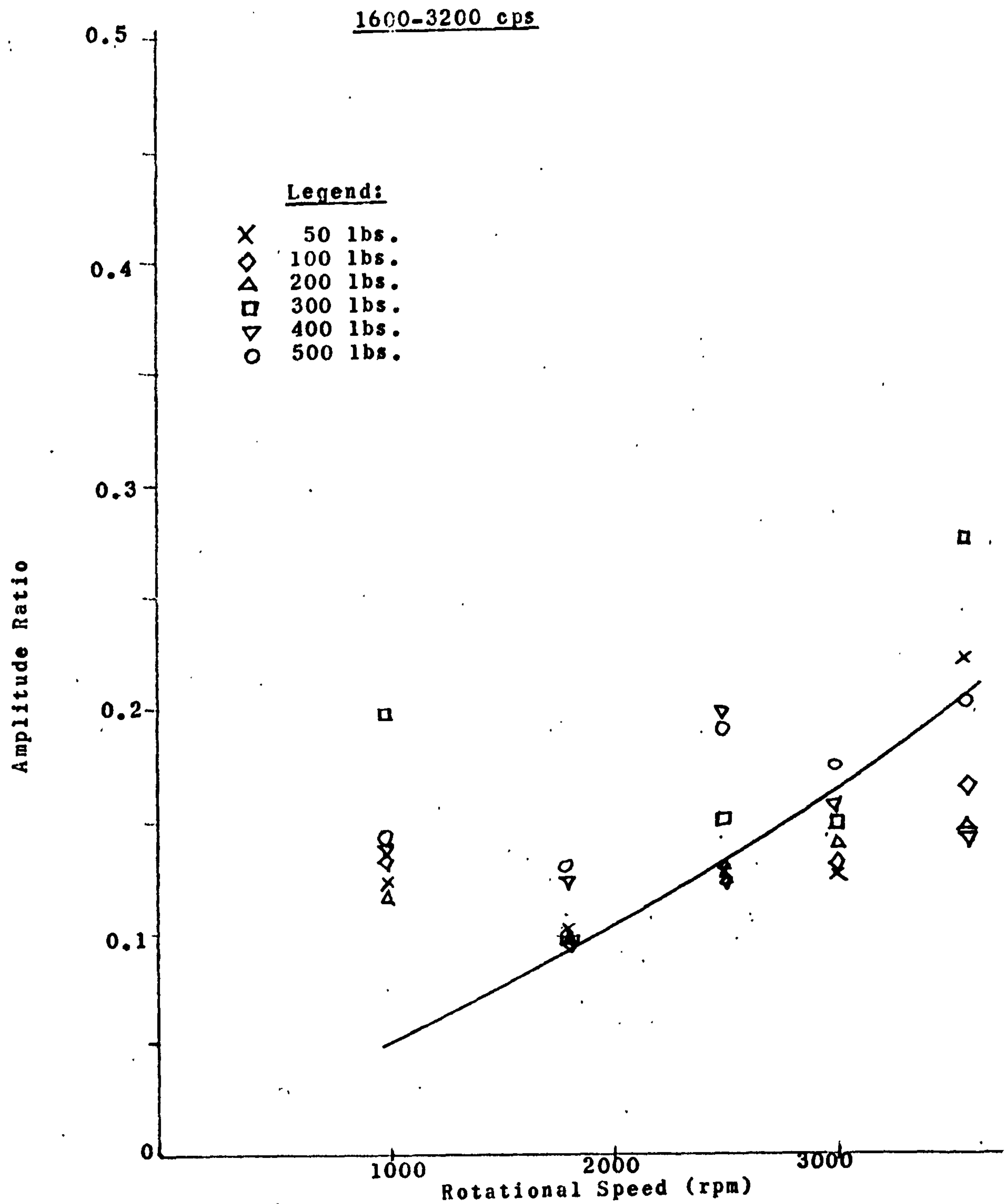
ENCLOSURE 11 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (200-400 cps FREQUENCY RANGE)



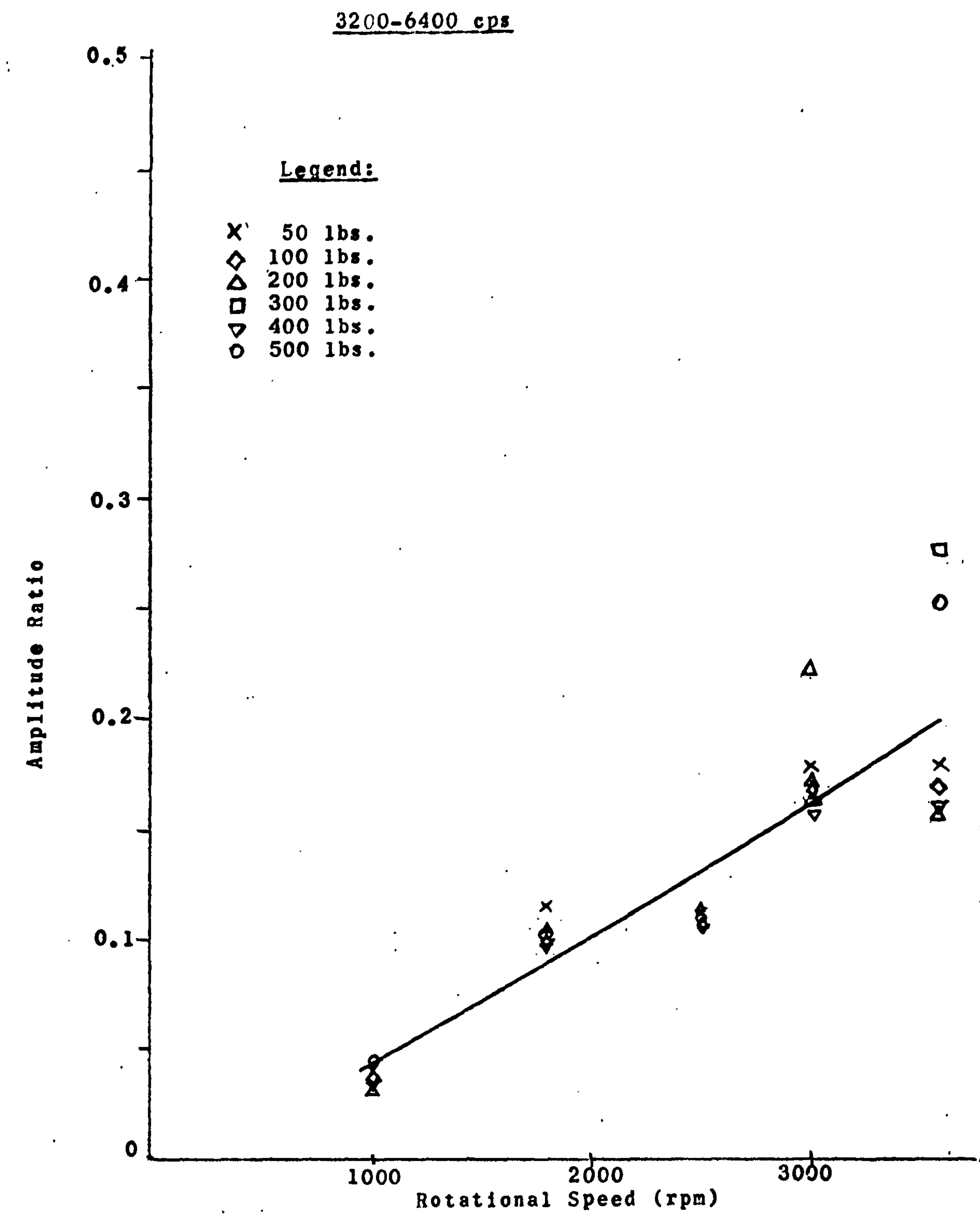
ENCLOSURE 12 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (400-800 cps FREQUENCY RANGE)



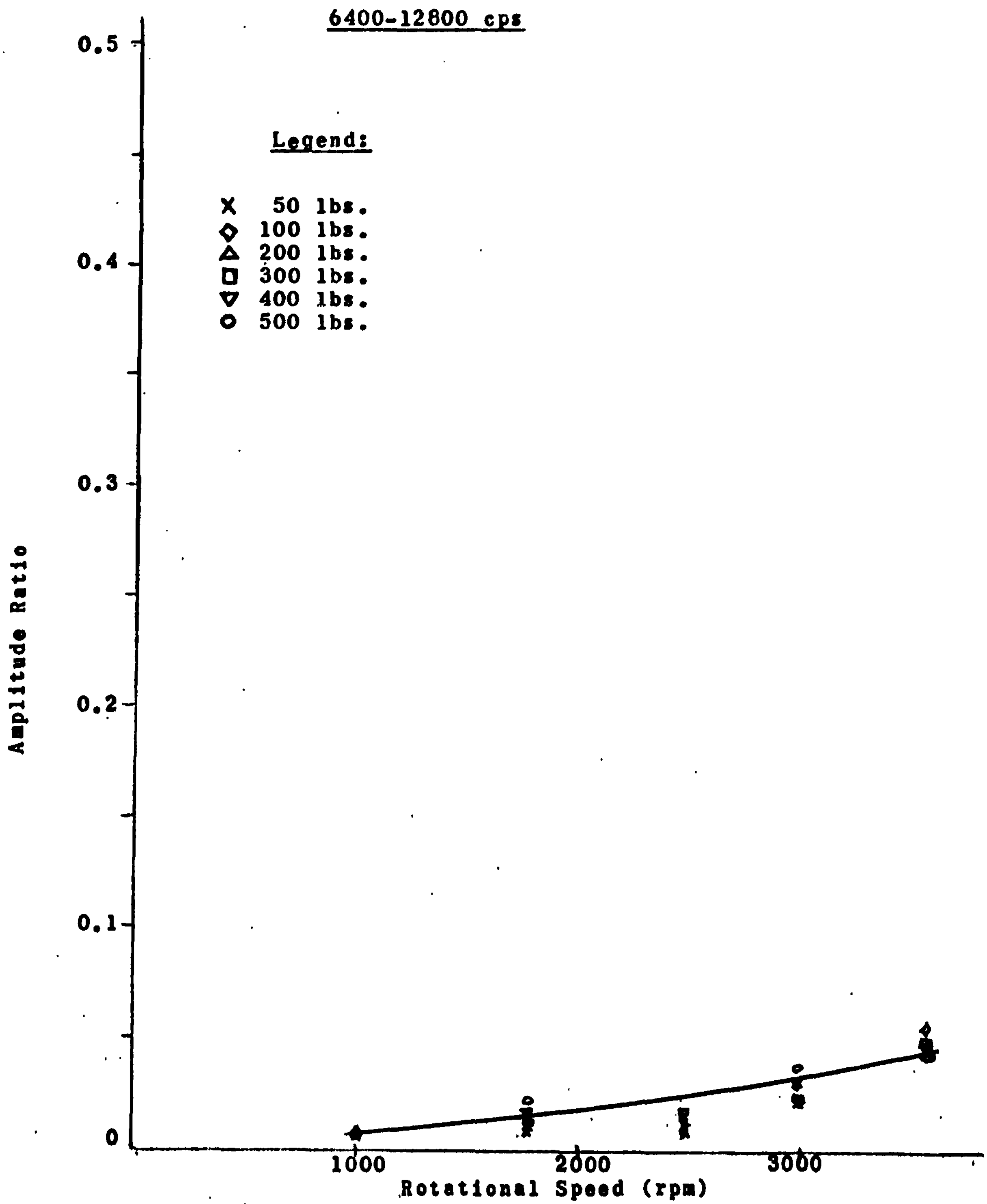
ENCLOSURE 13 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (800-1600 cps FREQUENCY RANGE)



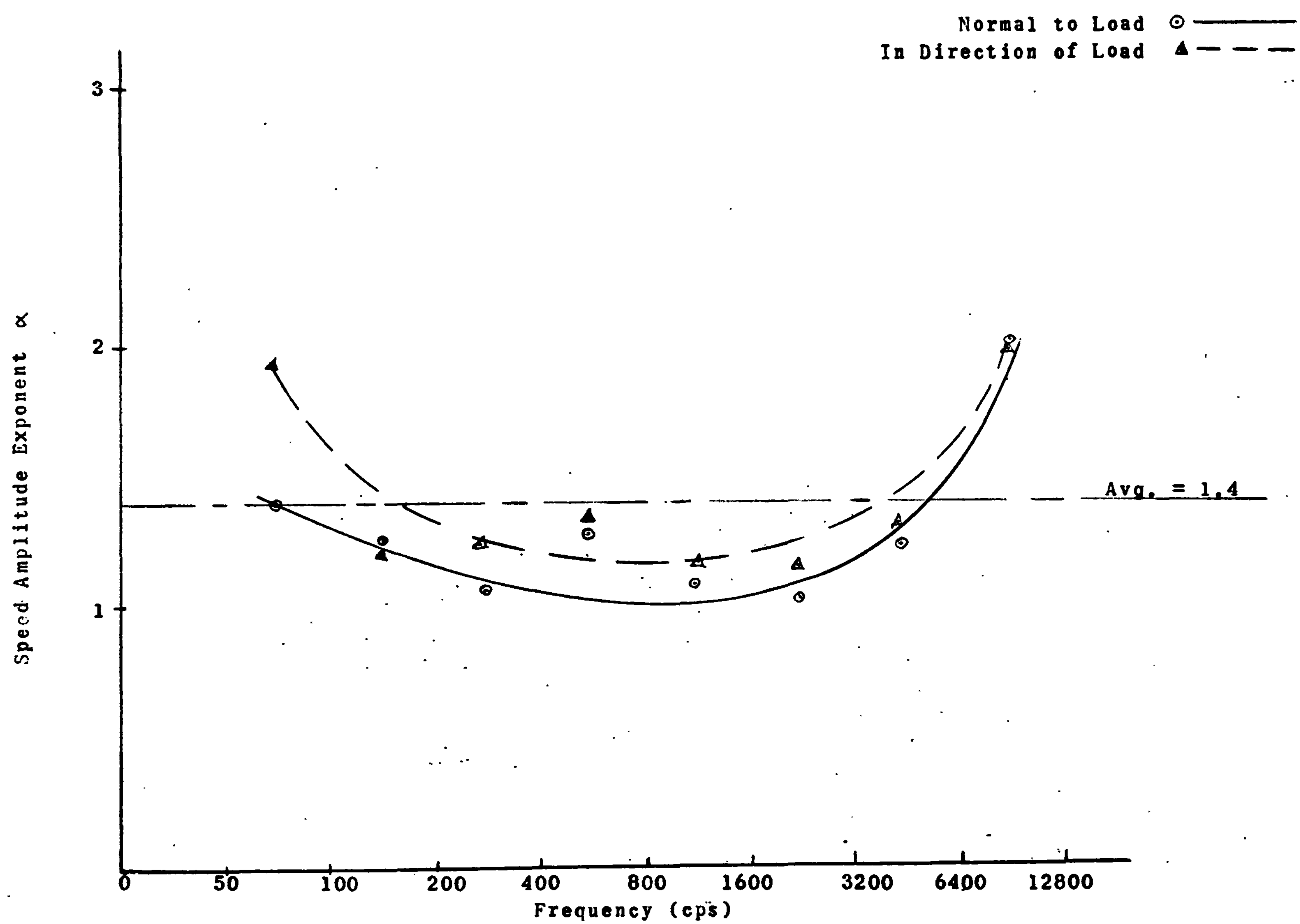
ENCLOSURE 14 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (1600-3200 cps FREQUENCY RANGE)



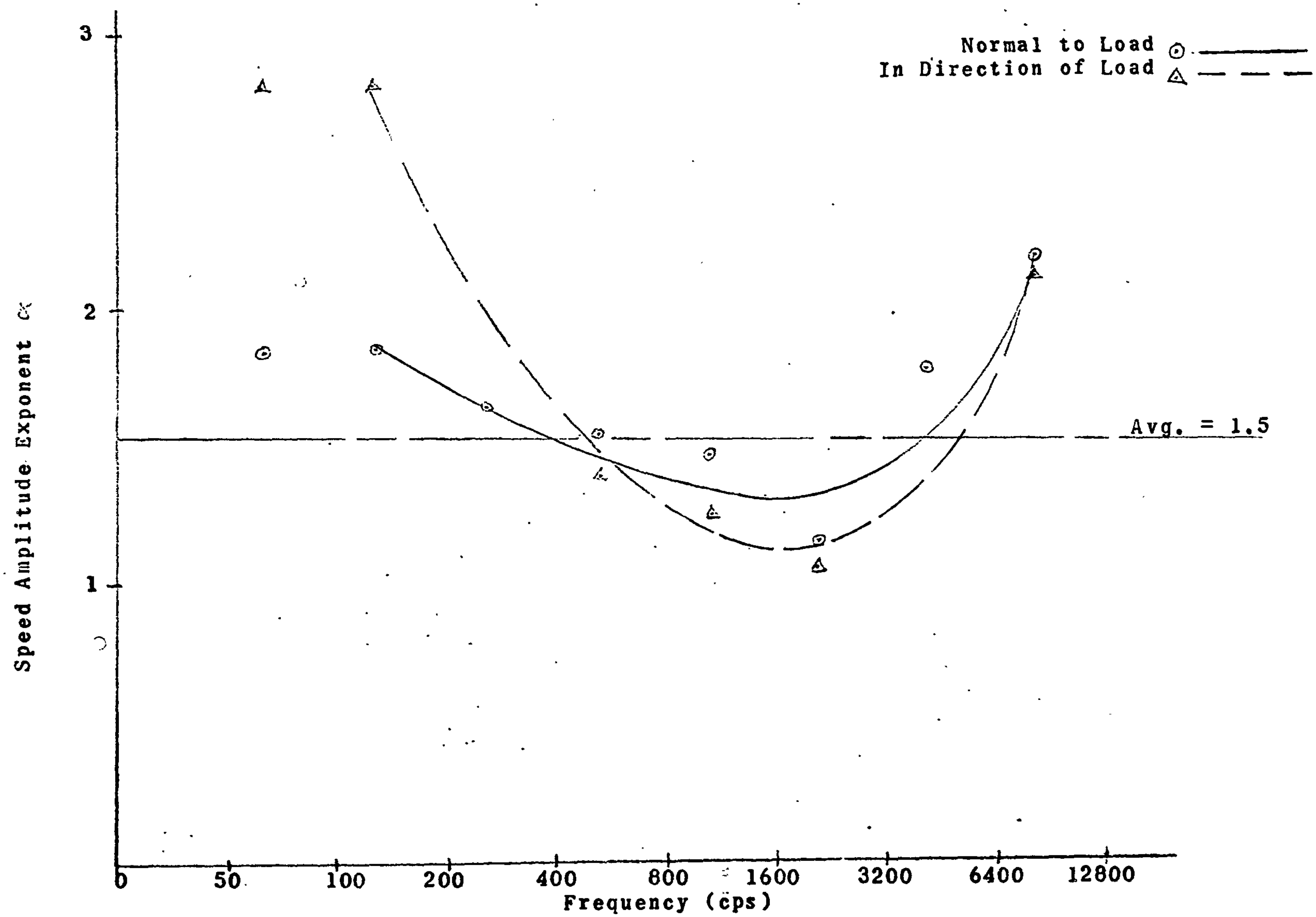
ENCLOSURE 15 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (3200-6400 cps FREQUENCY RANGE)



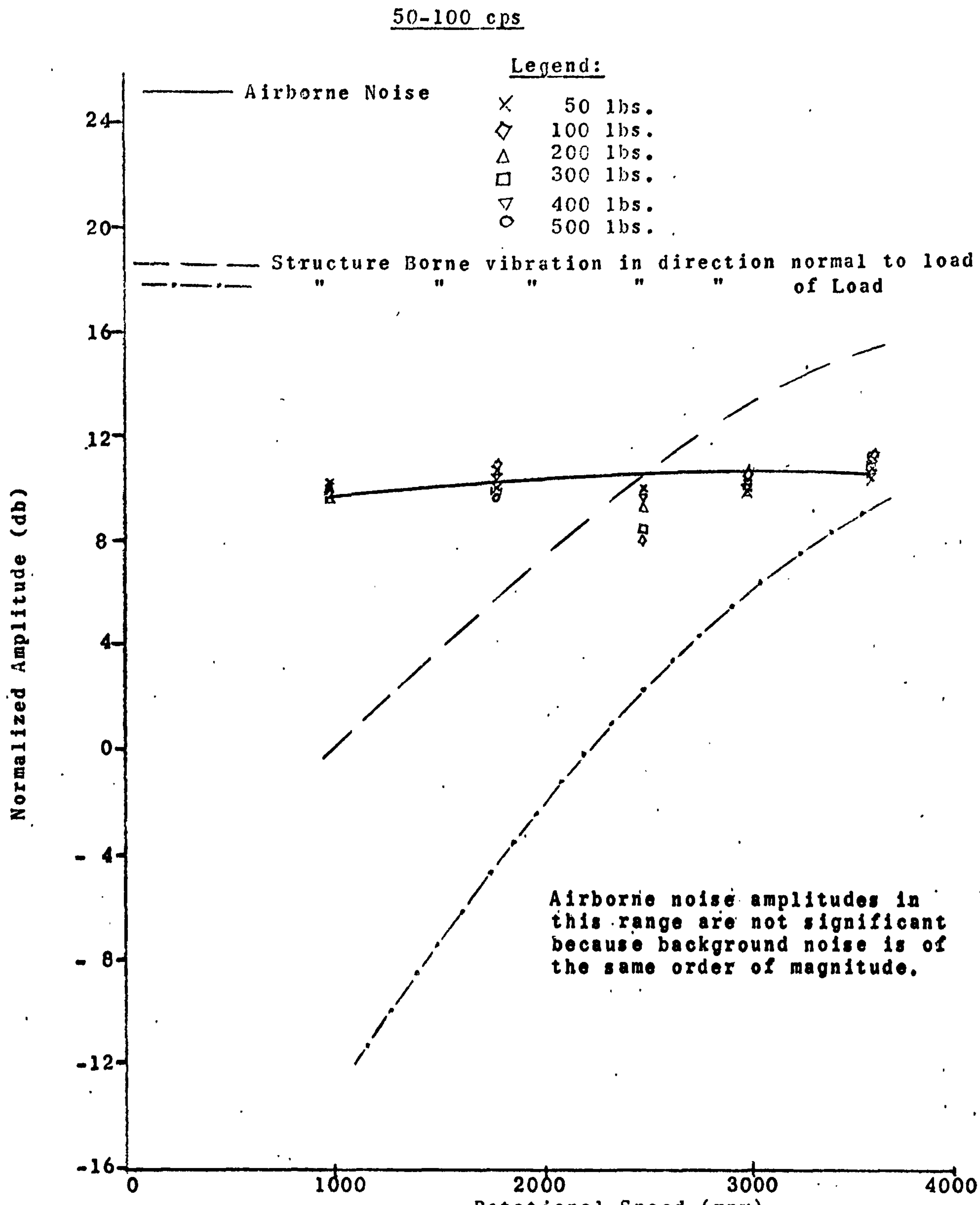
ENCLOSURE 16 STRUCTURE BORNE VIBRATION OF 6310 BEARINGS IN DIRECTION OF LOAD AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (6400-12800 cps FREQUENCY RANGE)



ENCLOSURE 17a SPEED AMPLITUDE EXPONENT FOR FREQUENCY BANDS OF 6310 SIZE BEARINGS

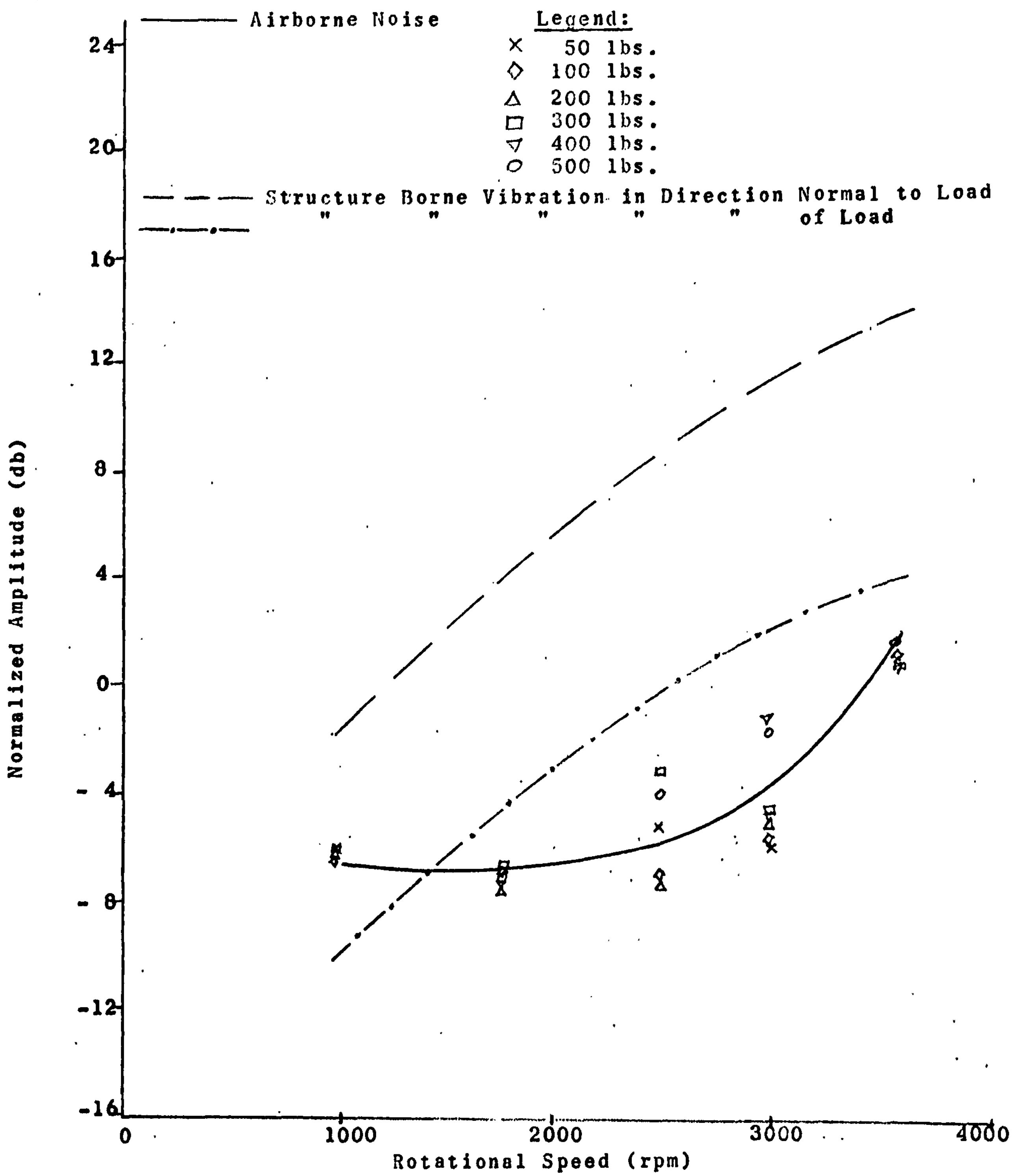


<u>ENCLOSURE 17b</u> SPEED AMPLITUDE EXPONENT FOR FREQUENCY BANDS OF 6305 SIZE BEARINGS

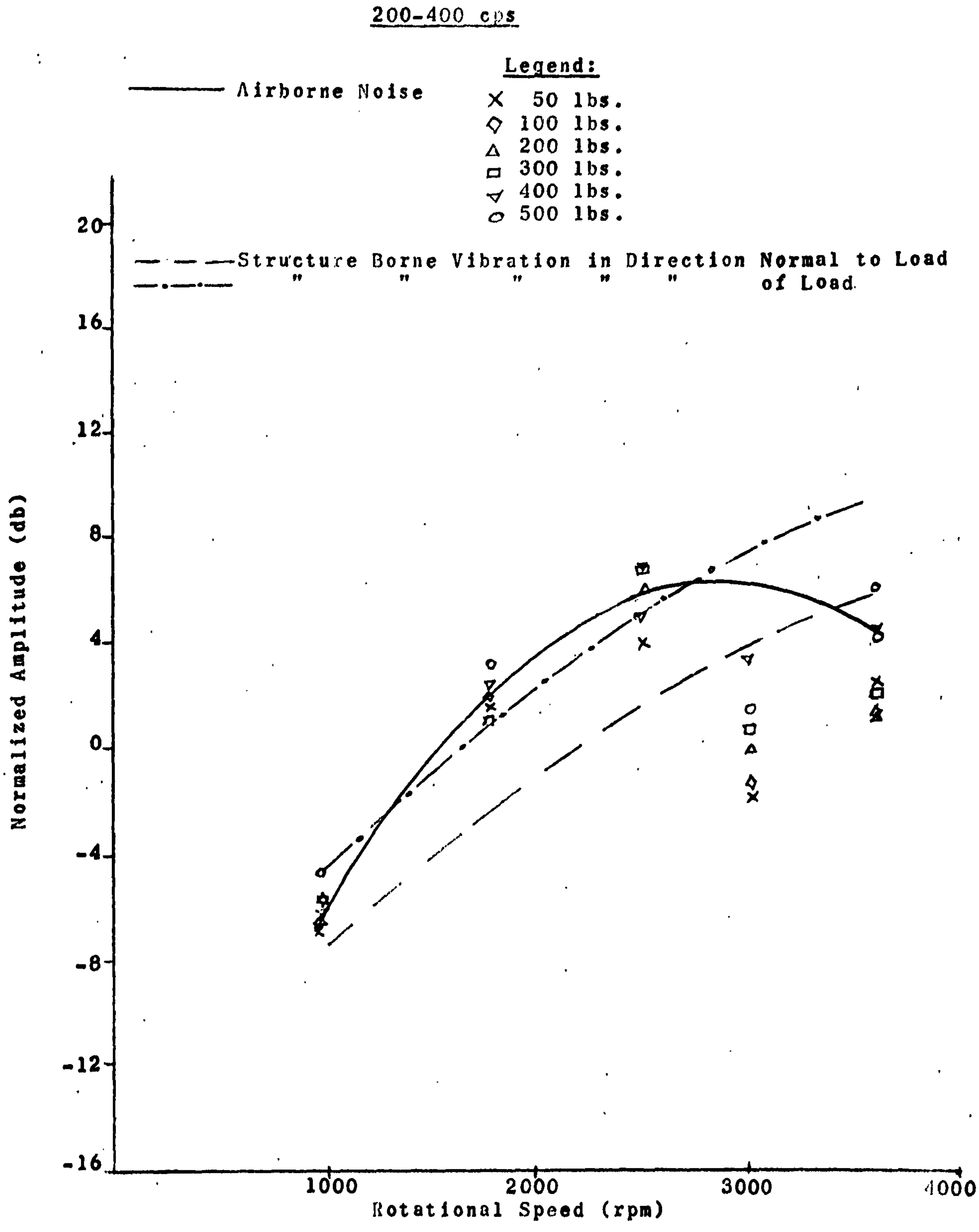


ENCLOSURE 18 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (50-100 cps FREQUENCY RANGE)

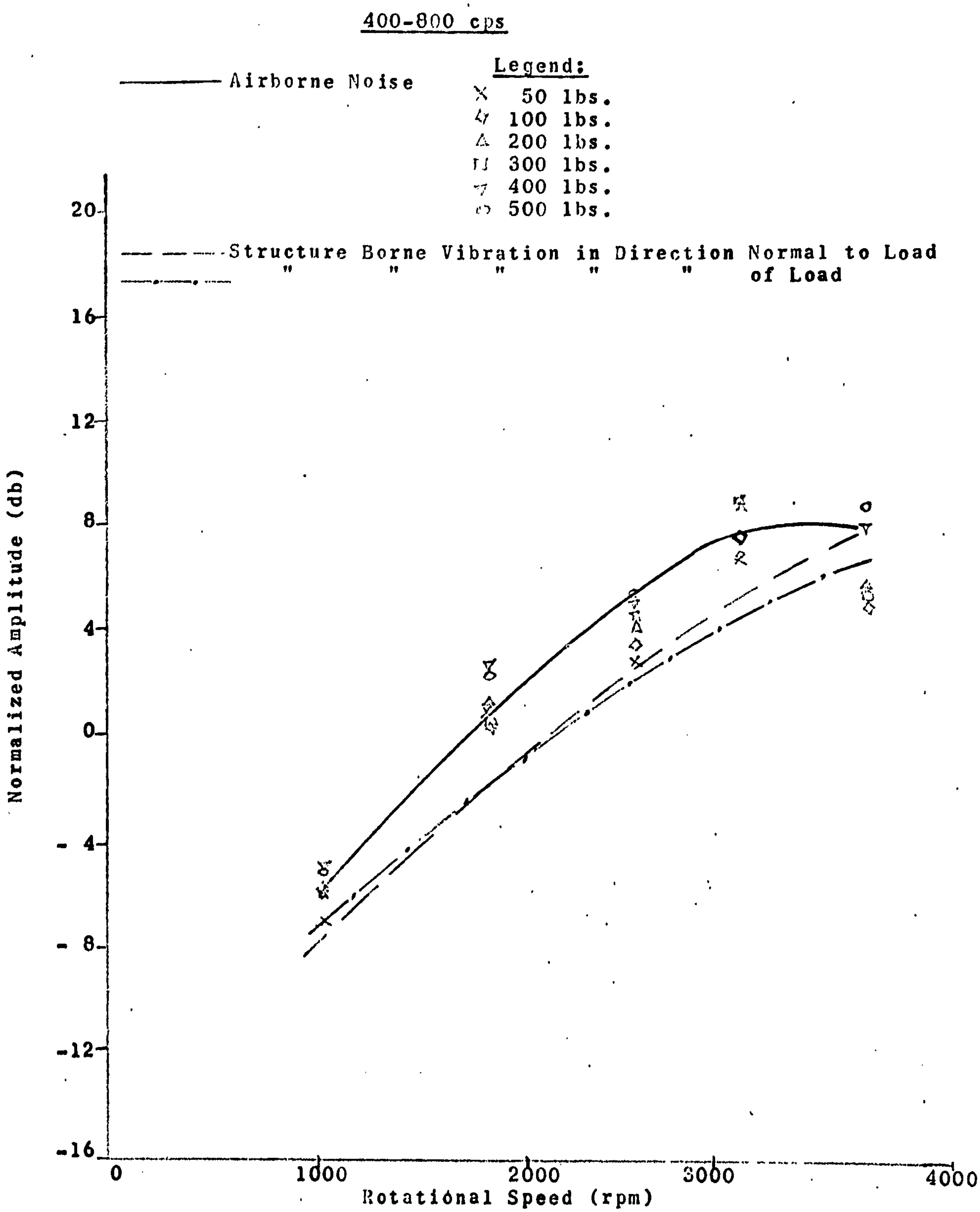
100-200 cps



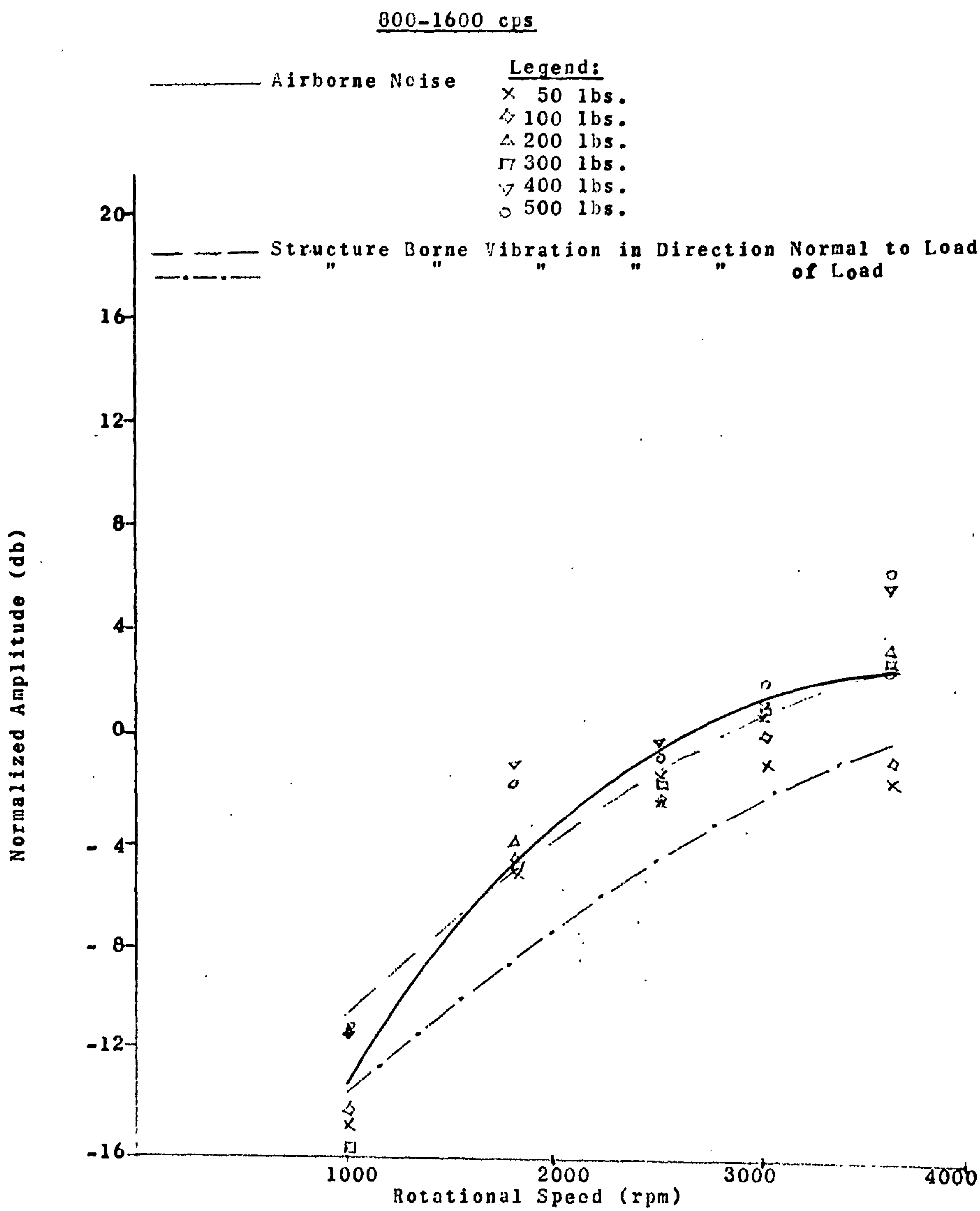
ENCLOSURE 19 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (100-200 cps FREQUENCY RANGE)



ENCLOSURE 20 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (200-400 cps FREQUENCY RANGE)

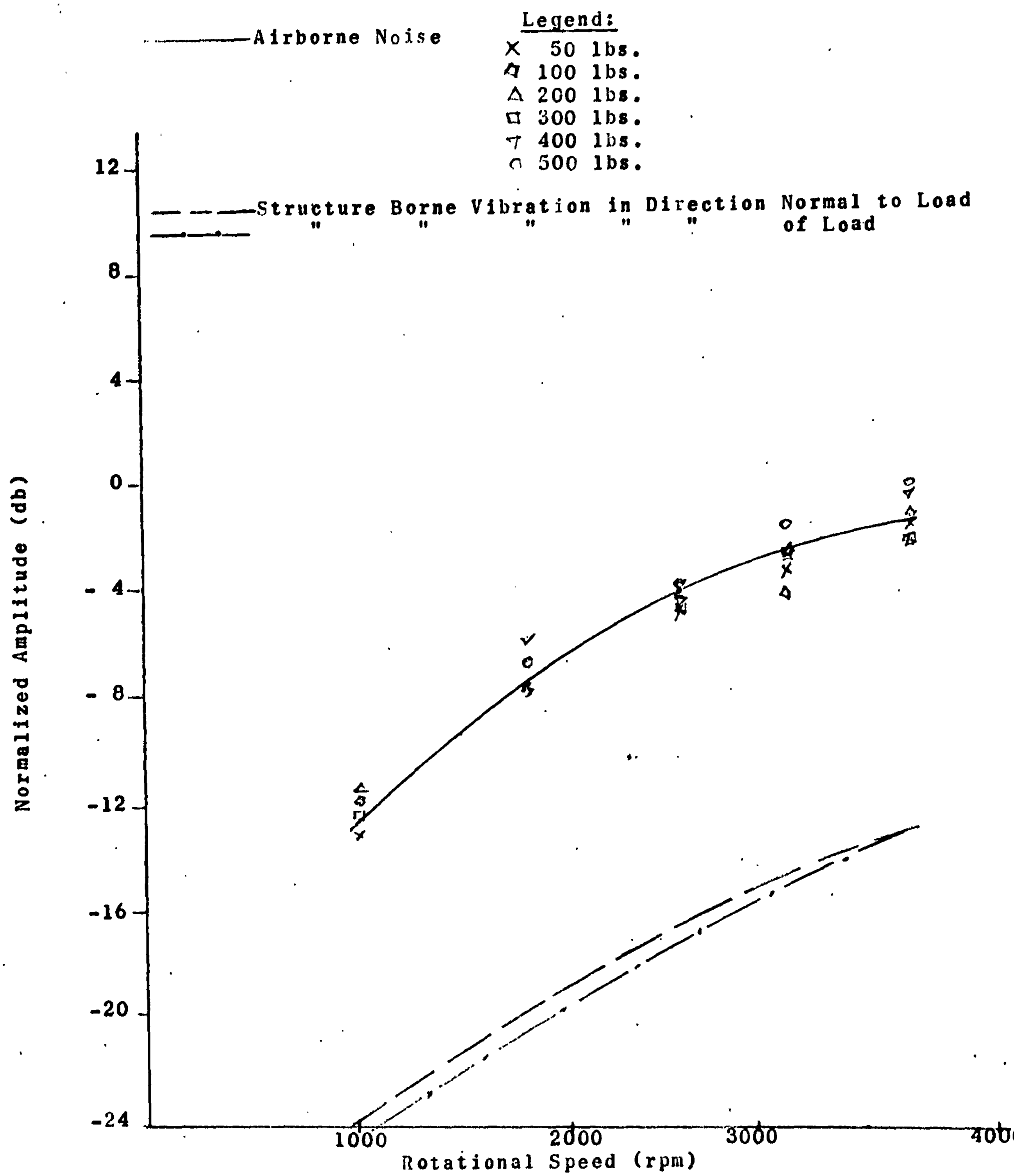


ENCLOSURE 21 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (400-800 cps FREQUENCY RANGE)



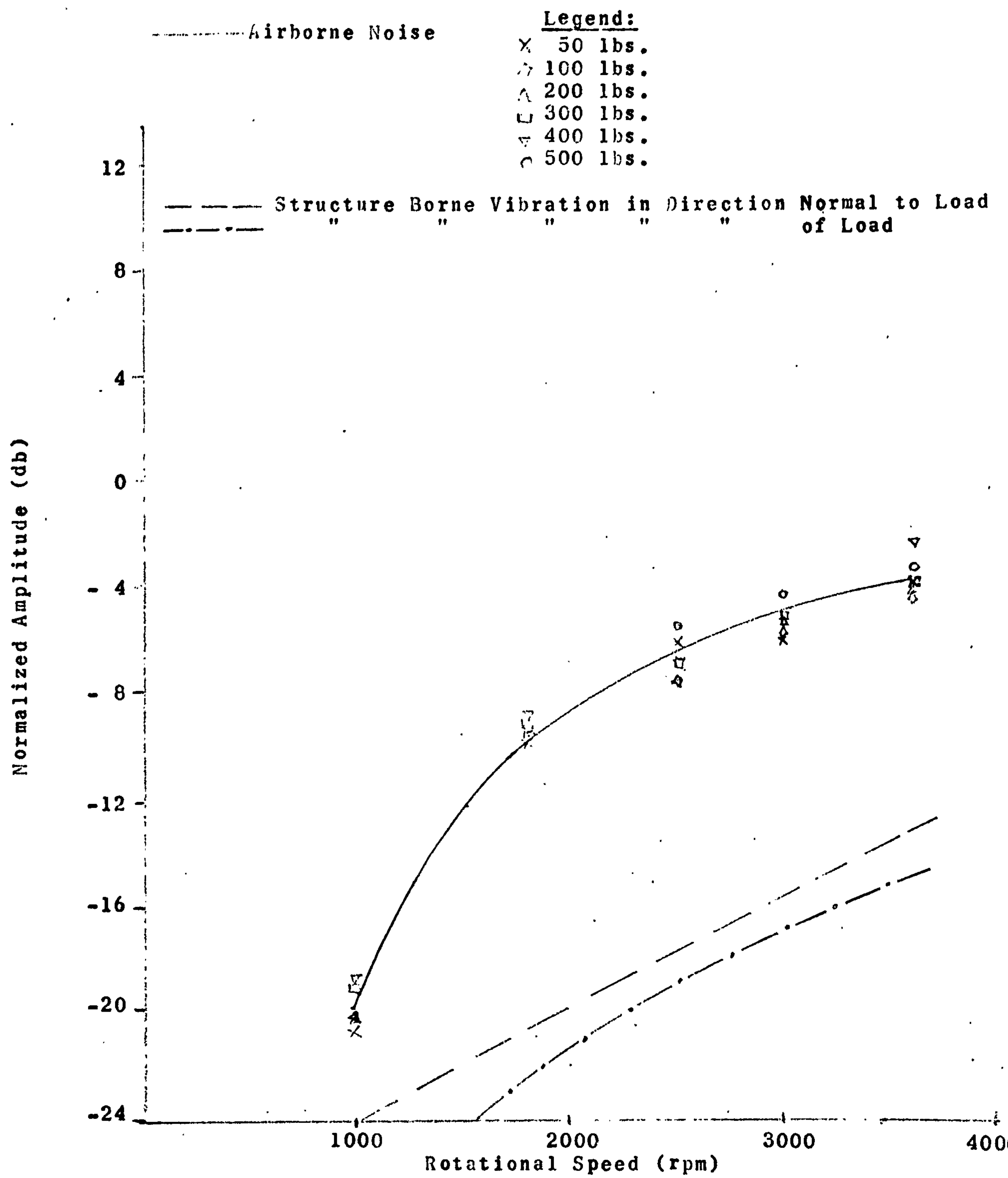
ENCLOSURE 22 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (800-1600 cps FREQUENCY RANGE)

1600-3200 cps

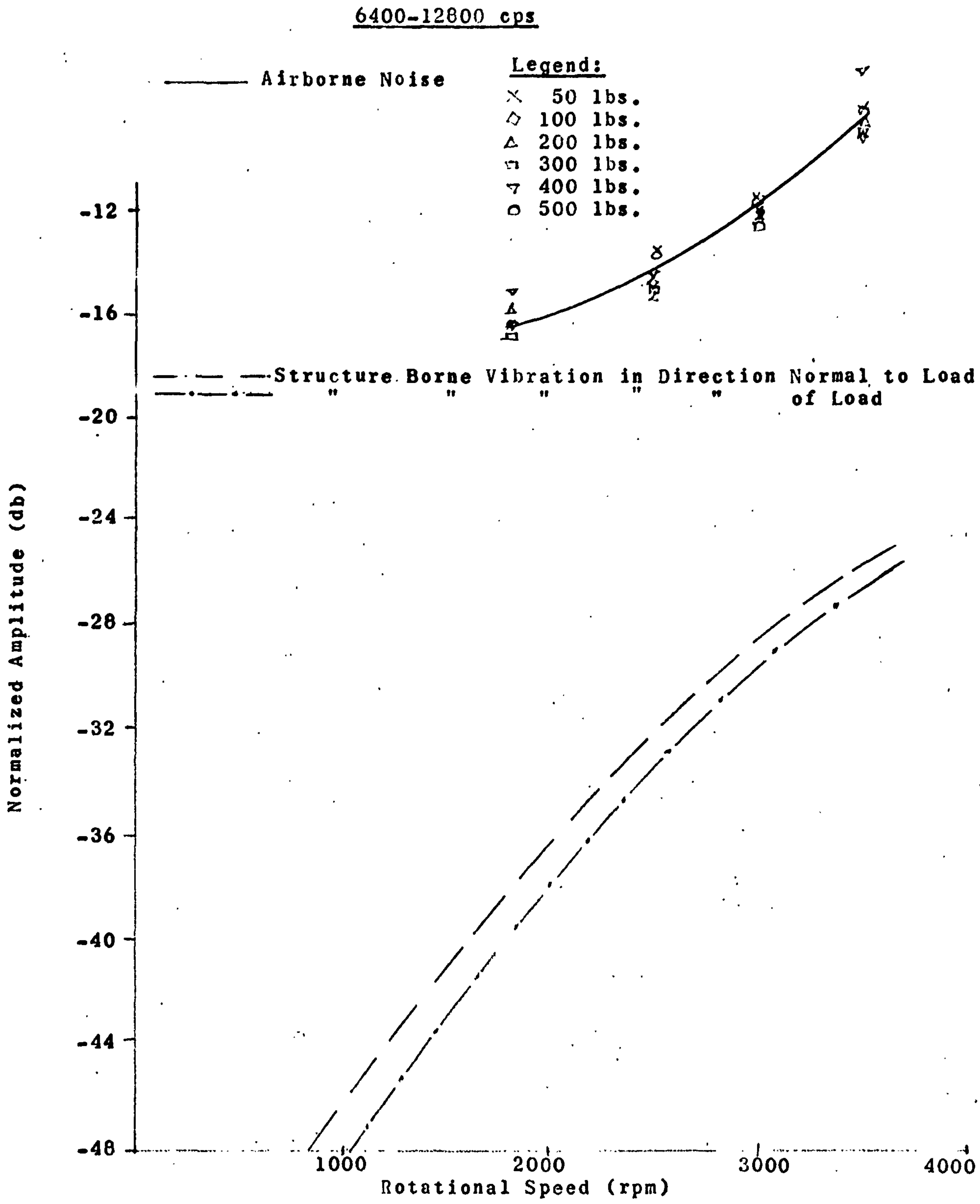


ENCLOSURE 23 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (1600-3200 cps FREQUENCY RANGE)

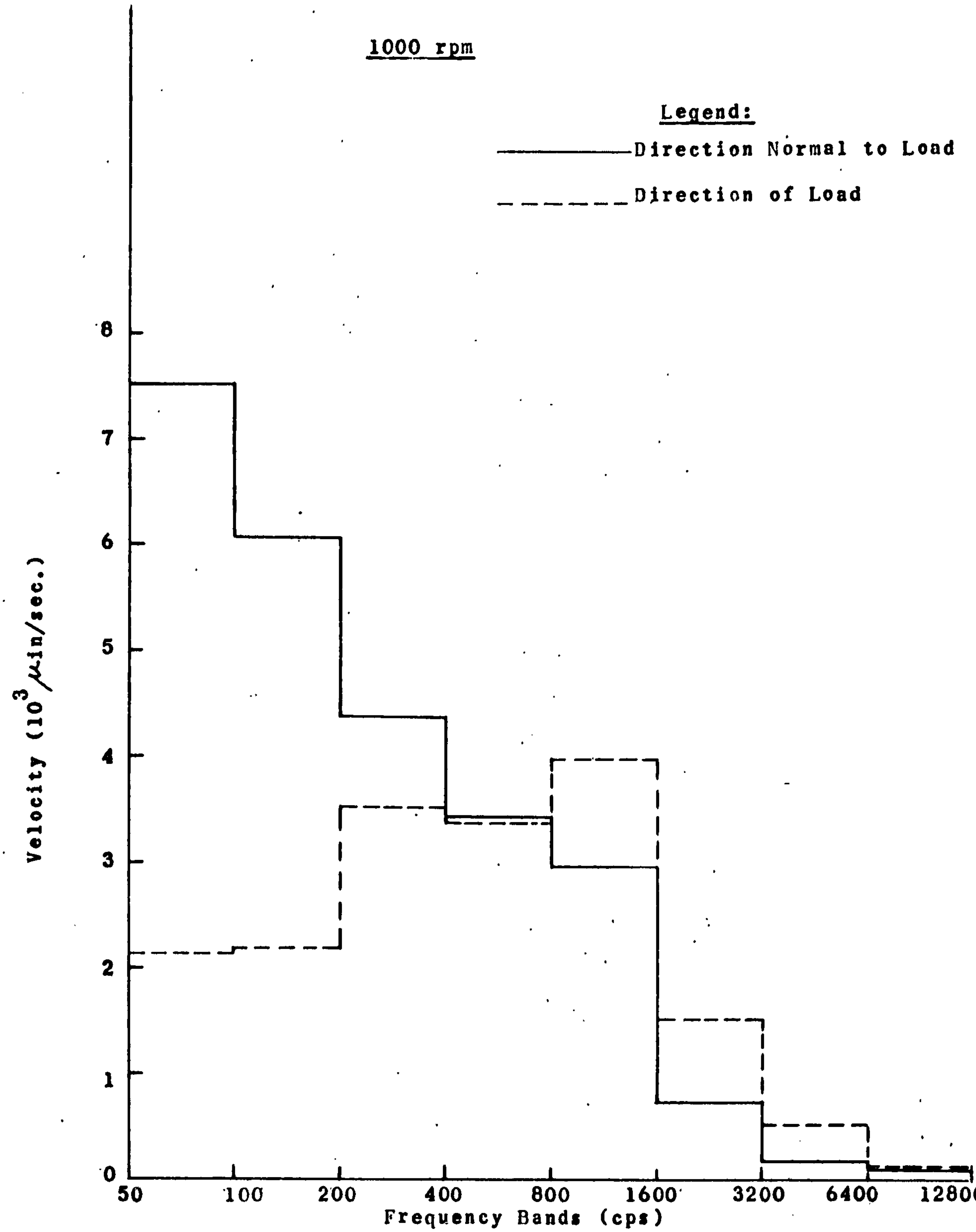
3200-6400 cps



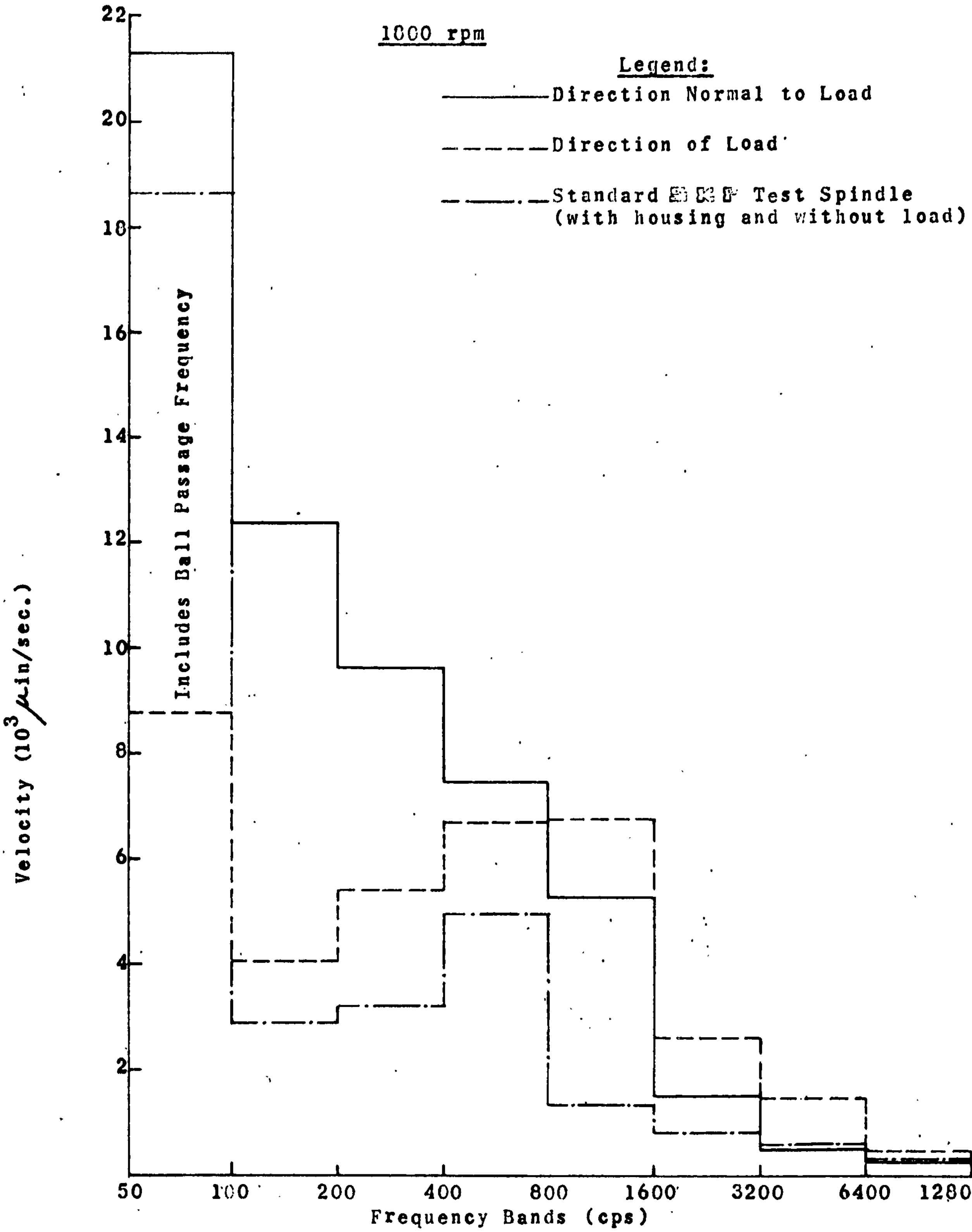
ENCLOSURE 24 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (3200-6400 cps FREQUENCY RANGE)



ENCLOSURE 25 AMPLITUDE OF AIRBORNE NOISE (AND STRUCTURE BORNE VIBRATIONS) AS A FUNCTION OF RADIAL LOAD AND ROTATIONAL SPEED (6400-12800 cps FREQUENCY RANGE)

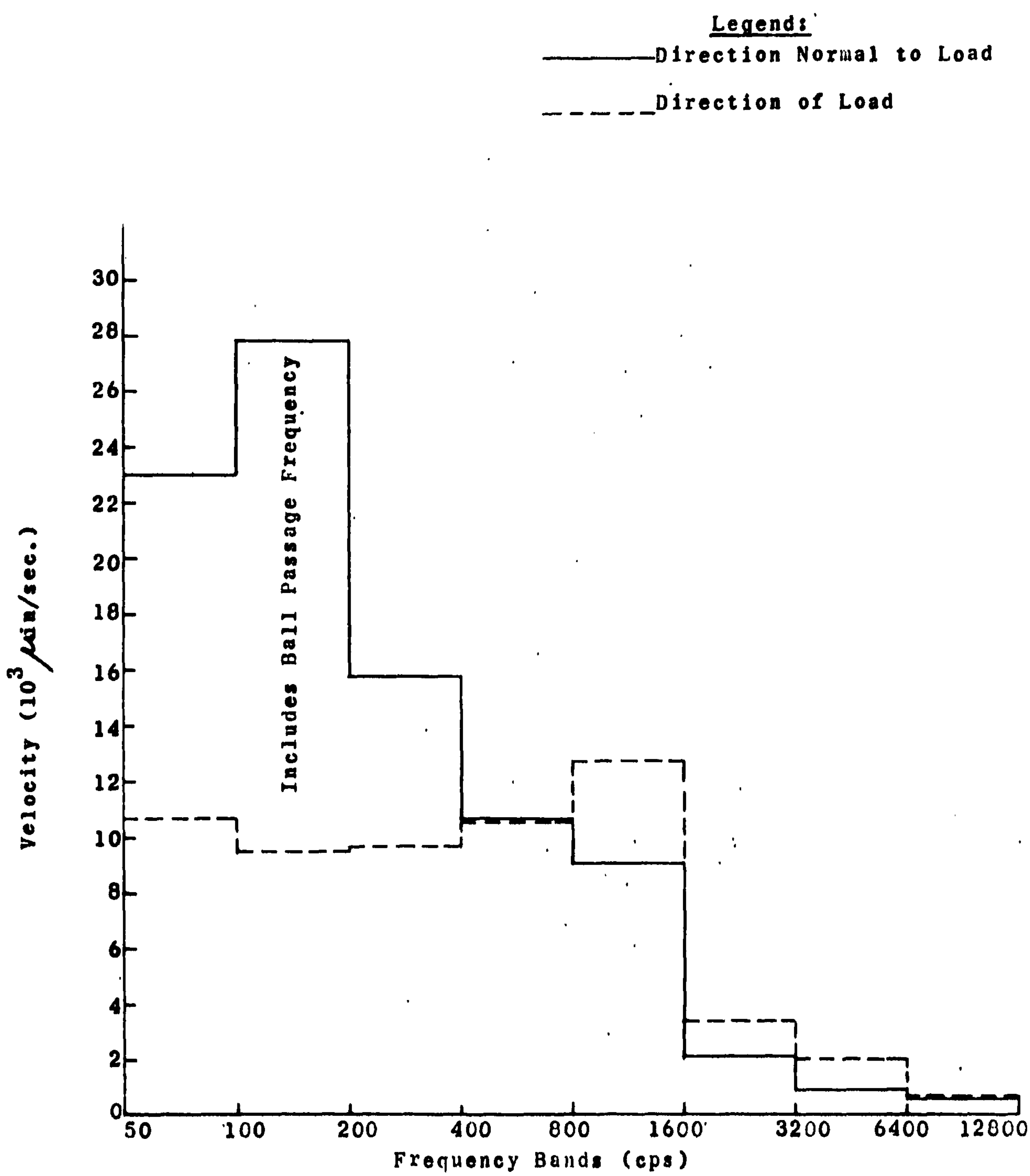


ENCLOSURE 26 OCTAVE BAND ANALYSIS OF 6305 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) 1000 RPM ROTATIONAL SPEED

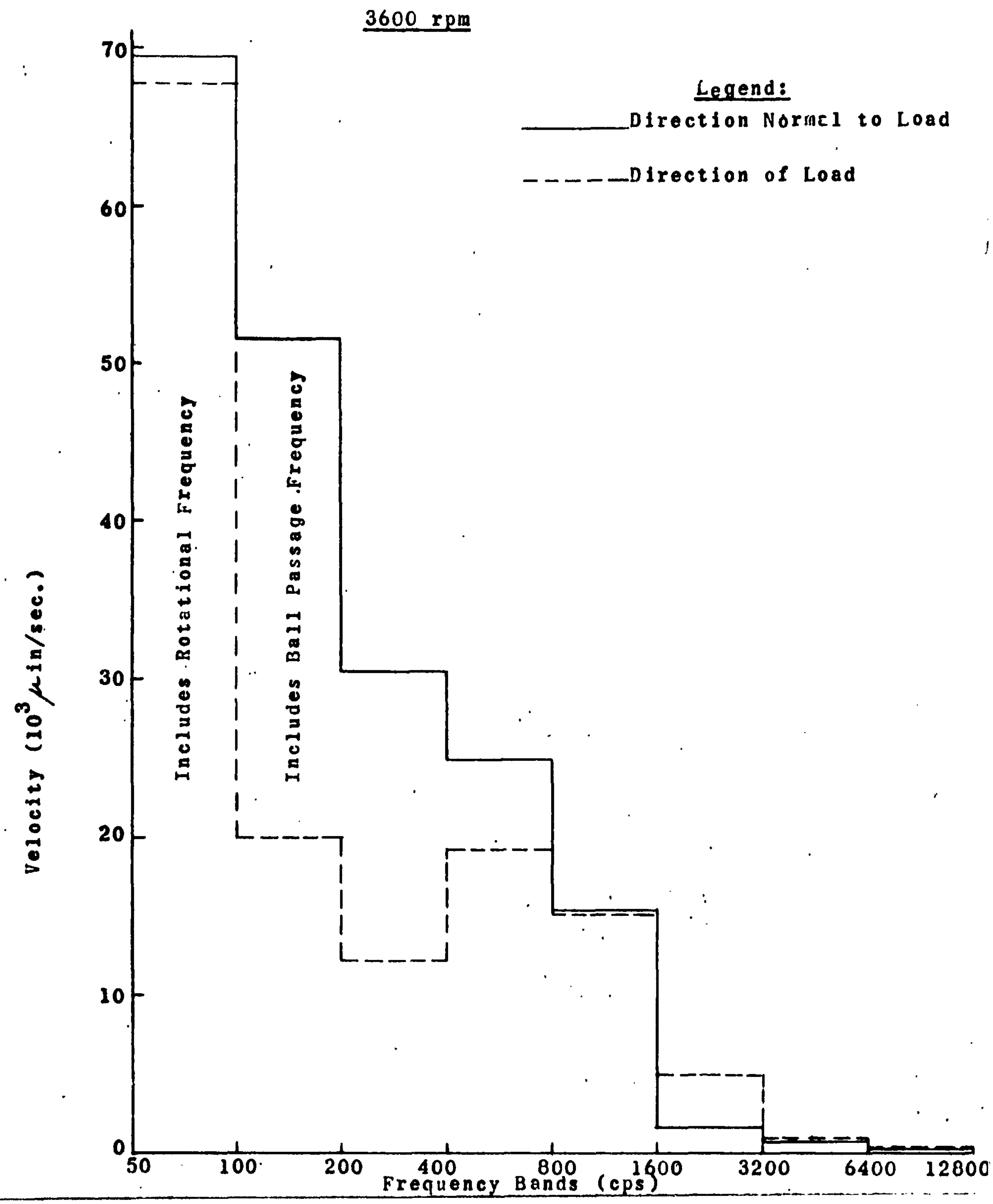


ENCLOSURE 27 OCTAVE BAND ANALYSIS OF 6305 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) 1800 RPM ROTATIONAL SPEED

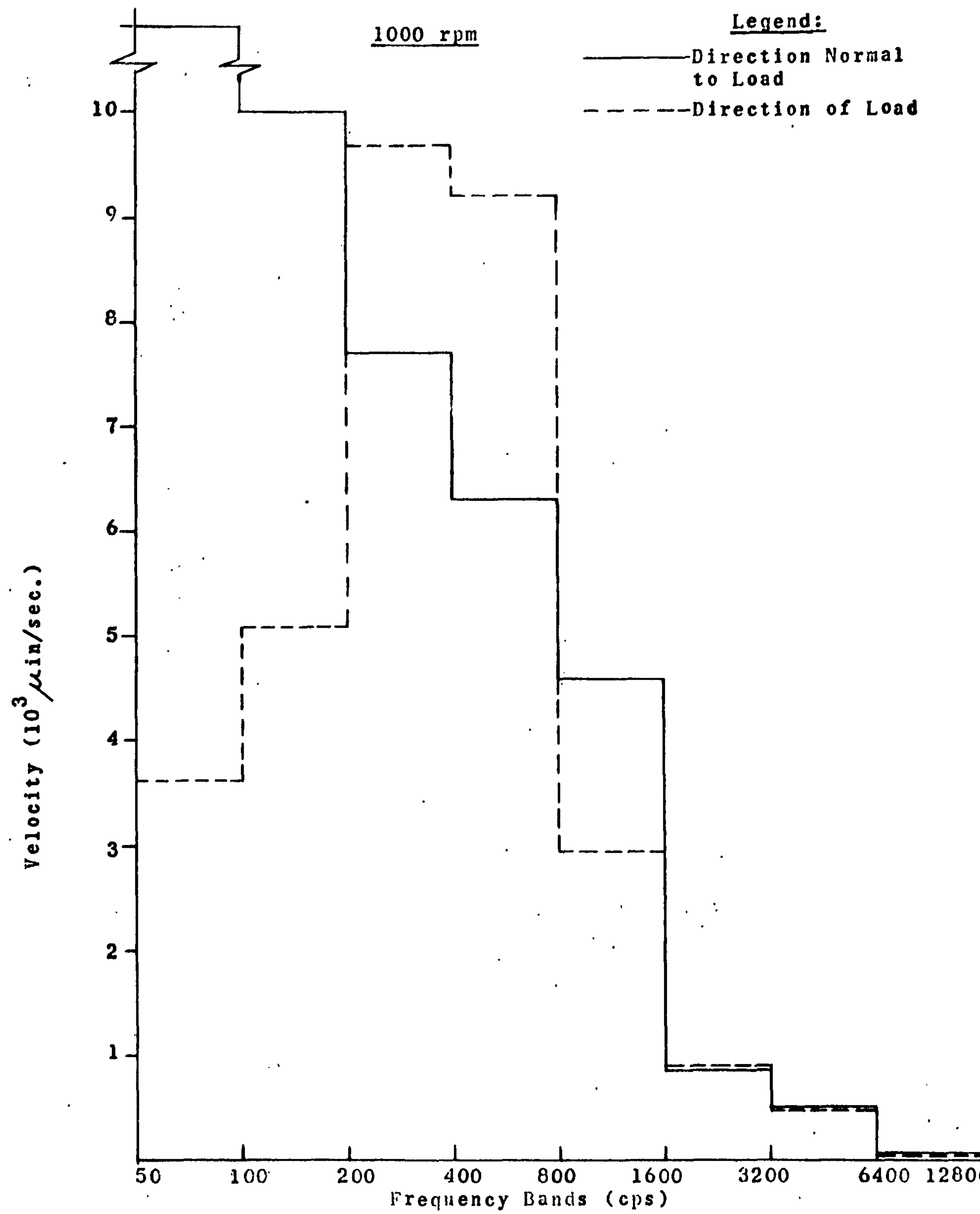
2500 rpm



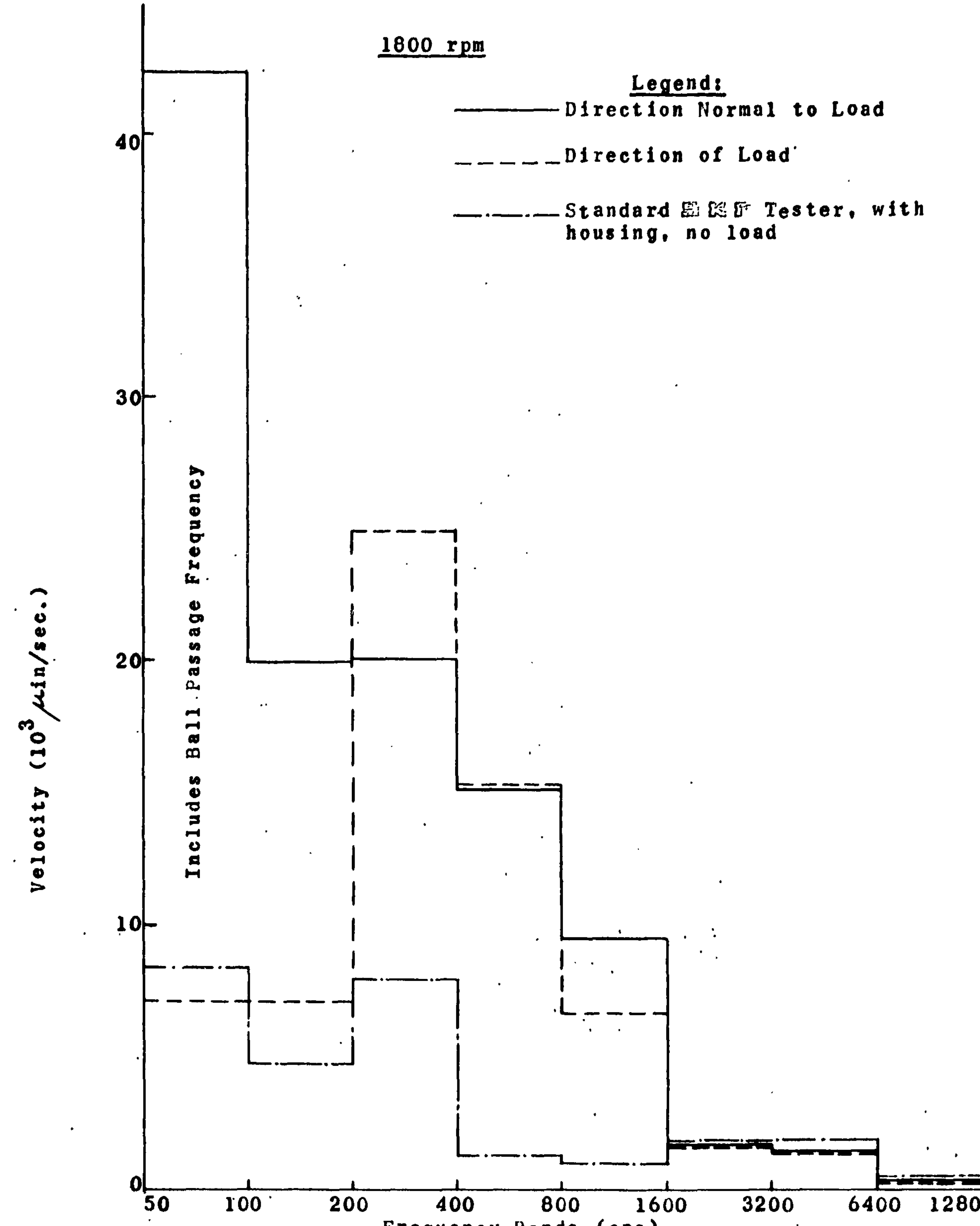
ENCLOSURE 28 OCTAVE BAND ANALYSIS OF 6305 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) 2500 RPM ROTATIONAL SPEED



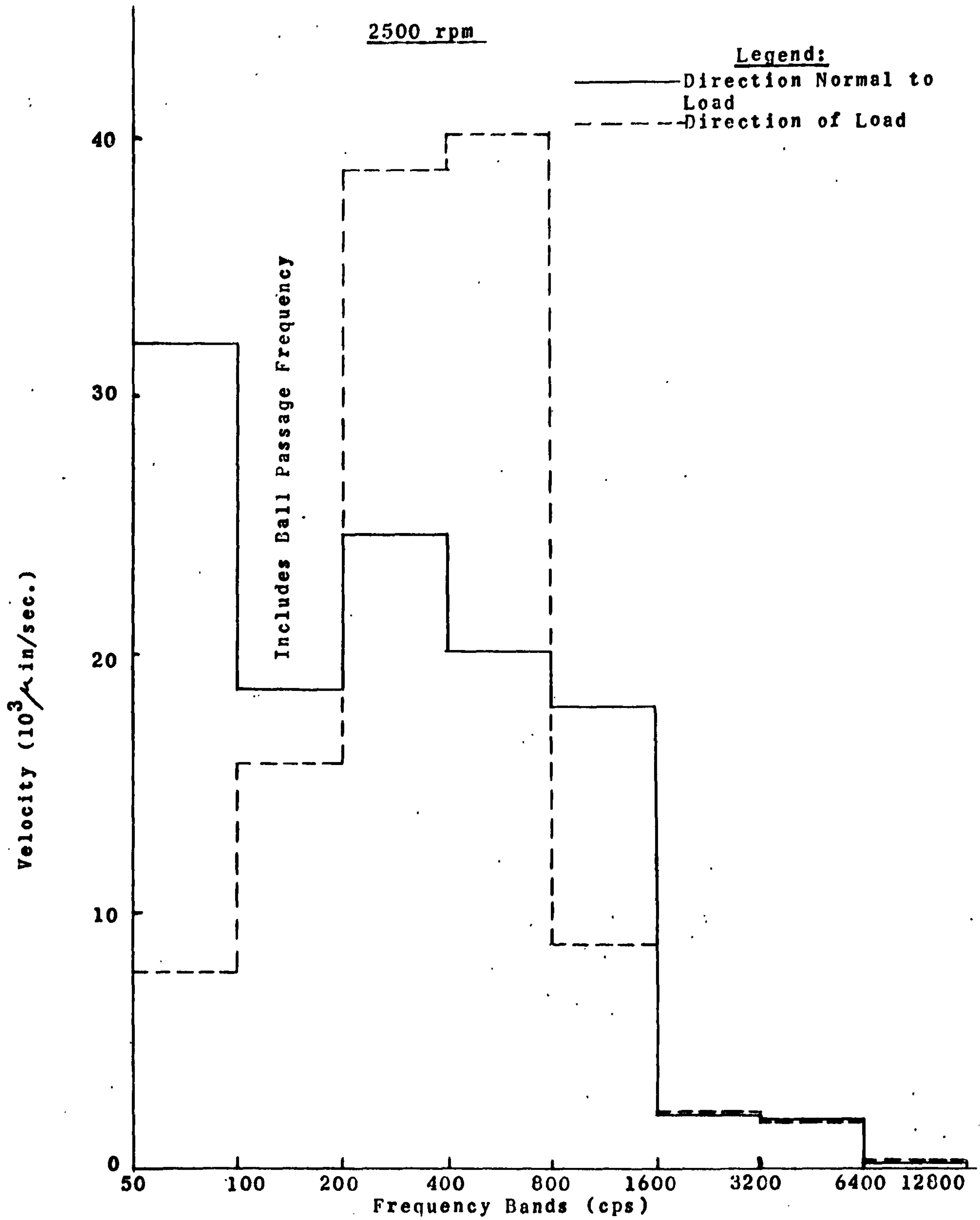
ENCLOSURE 29 - OCTAVE BAND ANALYSIS OF 6305 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) AT 3600 RPM ROTATIONAL SPEED



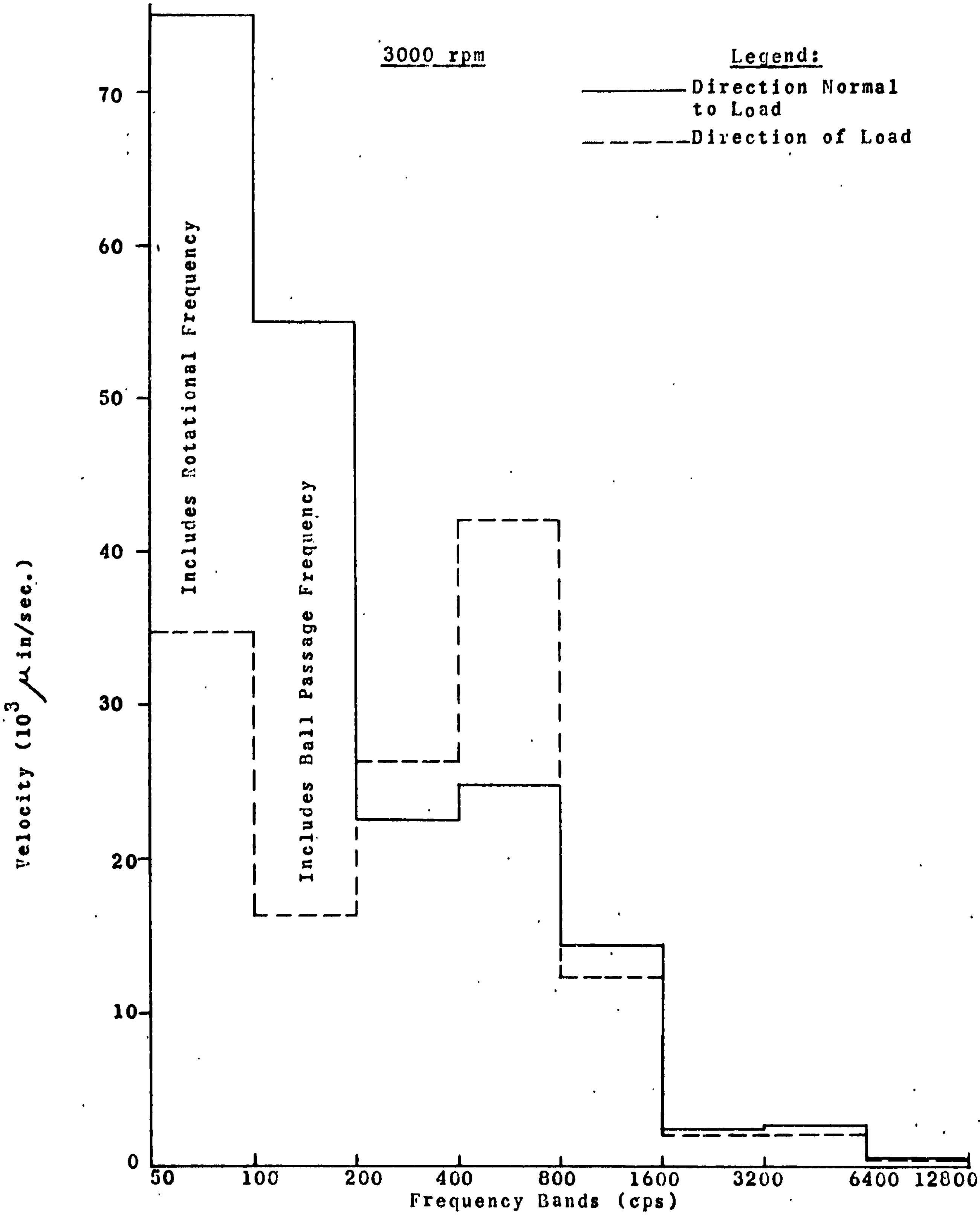
ENCLOSURE 30 OCTAVE BAND ANALYSIS OF 6310 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) AT 1000 RPM ROTATIONAL SPEED



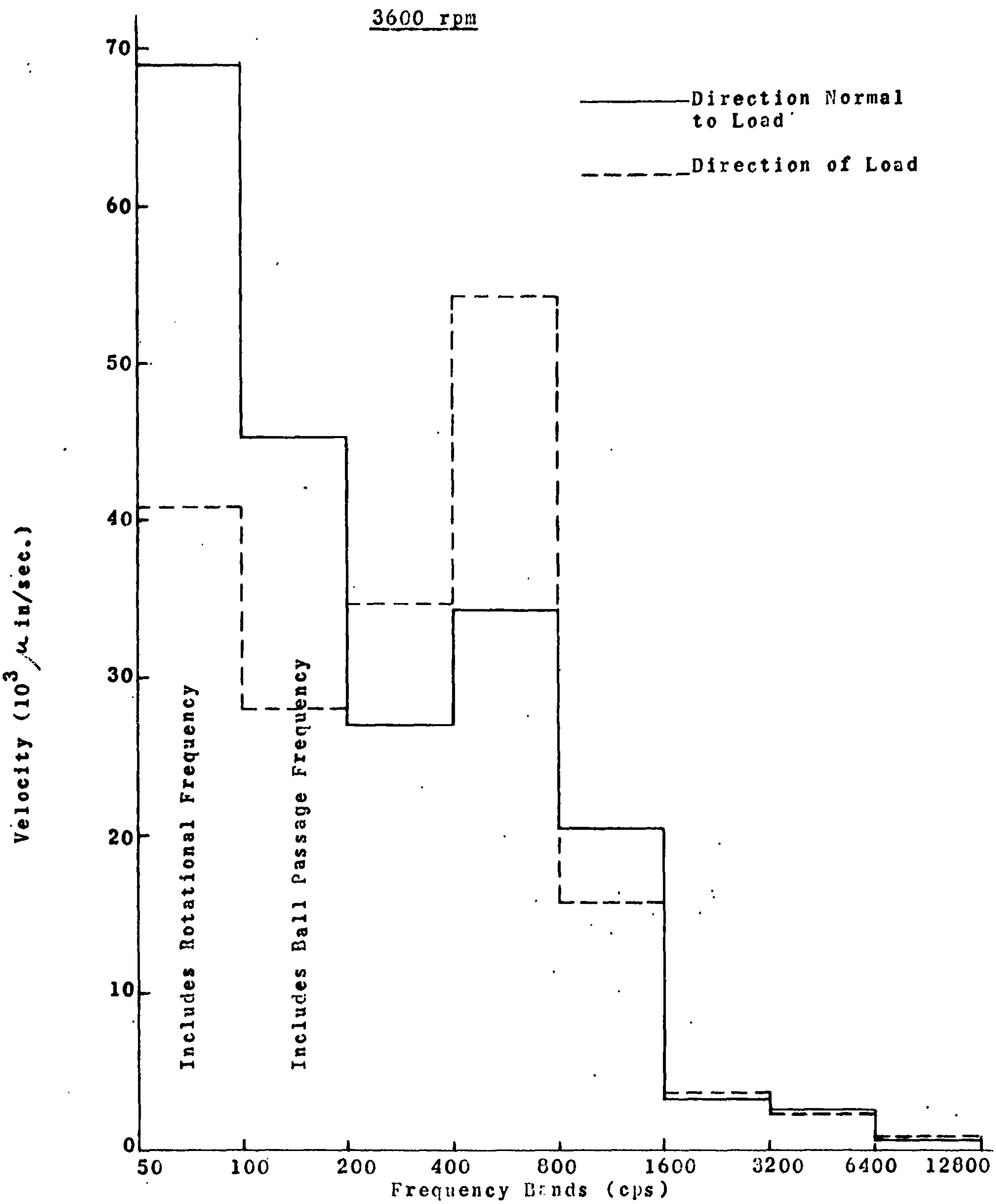
ENCLOSURE 31 OCTAVE BAND ANALYSIS OF 6310 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) AT 1800 RPM ROTATIONAL SPEED



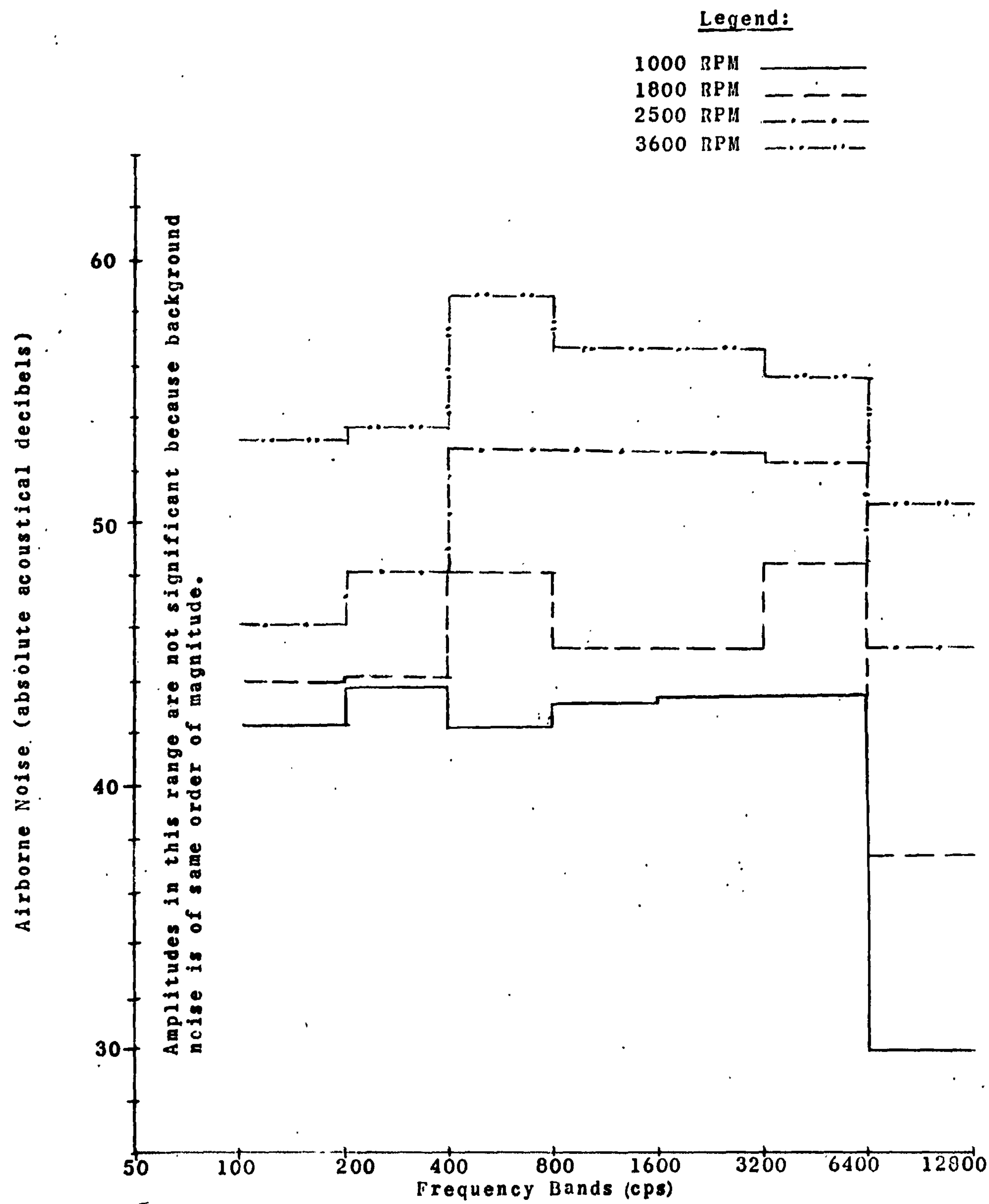
ENCLOSURE 32 OCTAVE BAND ANALYSIS OF 6310 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) 2500 RPM ROTATIONAL SPEED



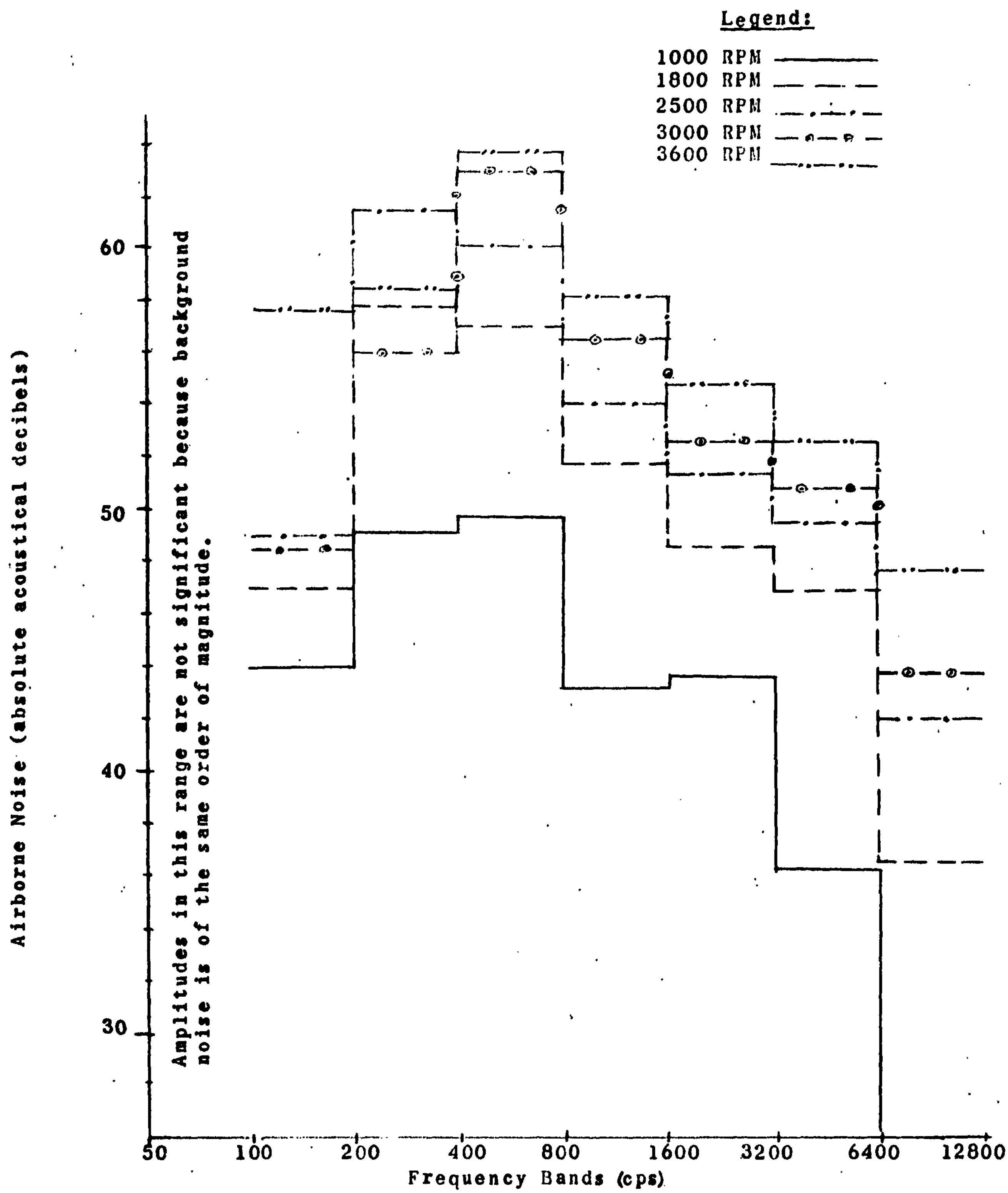
ENCLOSURE 33 OCTAVE BAND ANALYSIS OF 6310 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) AT 3000 RPM ROTATIONAL SPEED



ENCLOSURE 34 OCTAVE BAND ANALYSIS OF 6310 BEARING STRUCTURE BORNE VIBRATION IN ABSOLUTE UNITS (AVERAGE OF 6 LOADS) AT 3600 RPM ROTATIONAL SPEED



ENCLOSURE 35 OCTAVE BAND ANALYSIS OF AIRBORNE NOISE GENERATED BY FOUR 6305 BEARINGS (IN ABSOLUTE UNITS, AVERAGE OF 5 SETS AND 6 LOADS)



ENCLOSURE 36 OCTAVE BAND ANALYSIS OF AIRBORNE NOISE GENERATED BY FOUR 6310 BEARINGS (IN ABSOLUTE UNITS, AVERAGE OF 5 SETS AND 6 LOADS)

ENCLOSURE 37

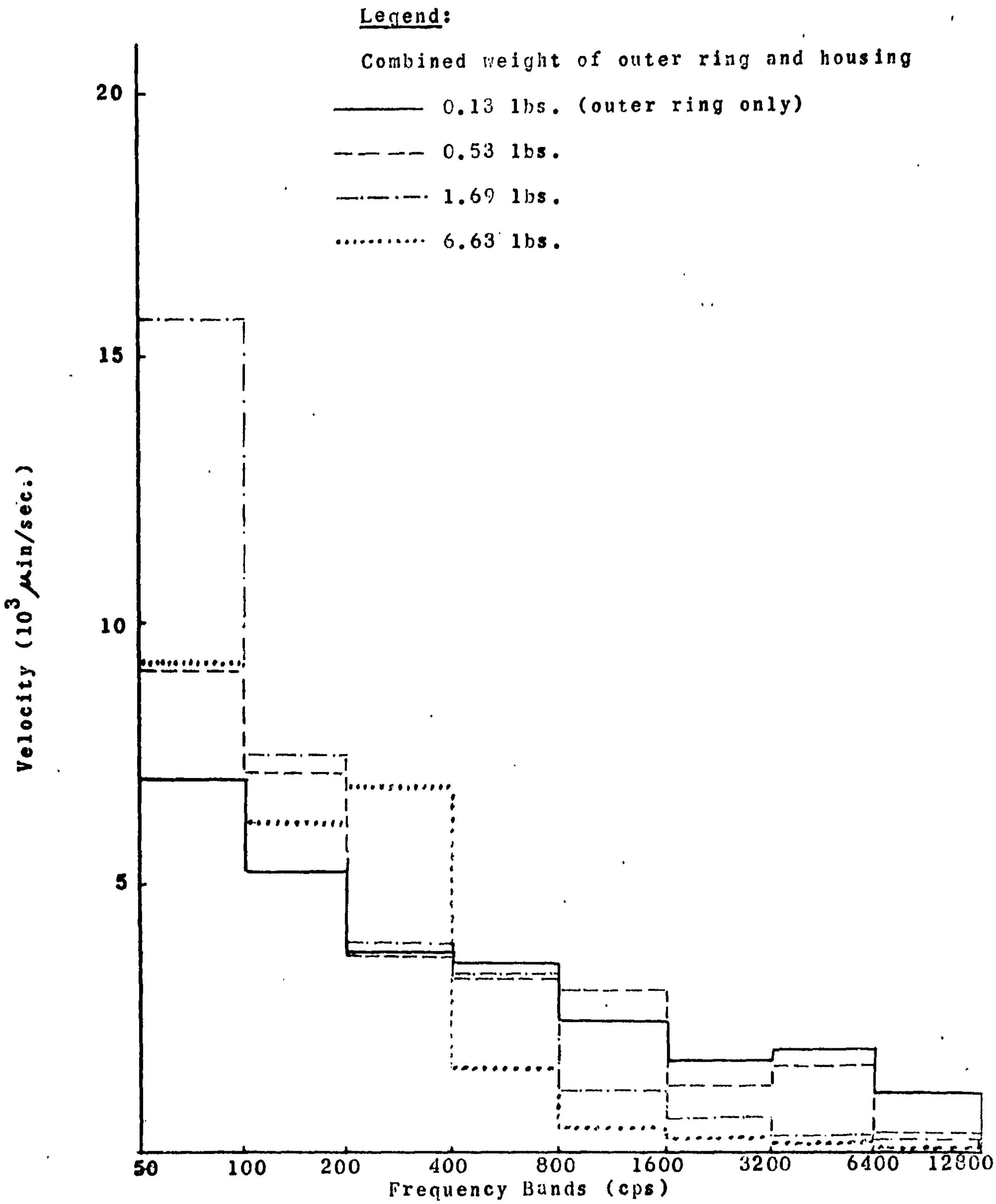
COMPARISON OF VIBRATION AND AIRBORNE NOISE LEVEL OF DIFFERENT SIZE BEARINGS

Ratio of 6310 to 6305 Bearing Vibration Levels Measured Under Radial Load (Navy Tester) (6310 bearing with 8.2 lbs. and 6305 bearing with 1.5 lbs. housing)

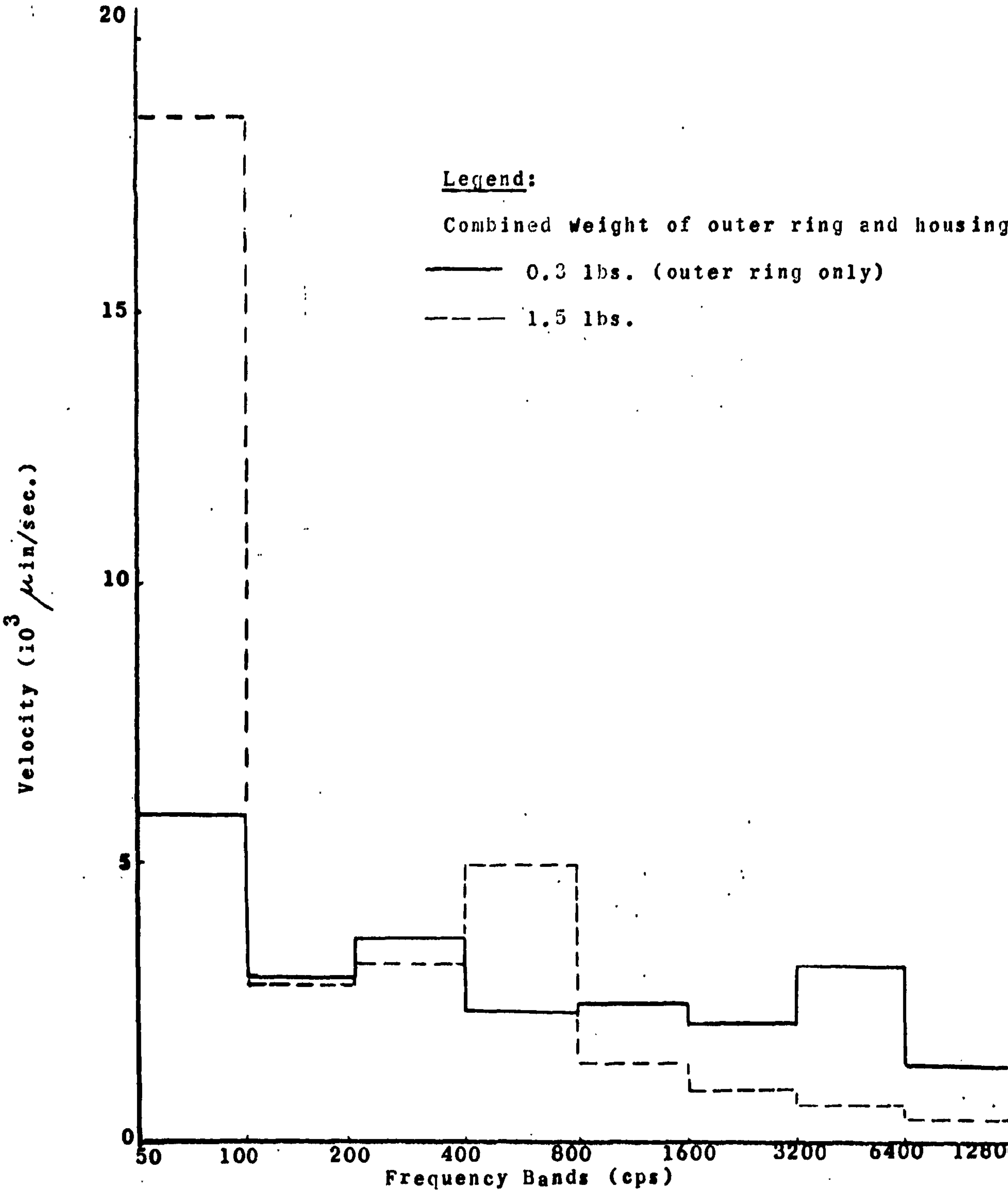
Rotational Speed rpm	50-100	100-200	200-400	400-800	800-1600	1600-3200	3200-6400	6400-12800 cps
TABLE A: Structure Borne Vibrations in Direction Normal to Load								
1000	1.7	1.6	1.8	1.8	1.6	1.1	2.5	0.5
1800	2.0	1.6	2.1	2.0	1.8	1.0	2.8	0.6
2500	1.4	0.7	1.5	1.9	2.0	1.0	2.0	0.5
3600	1.0	0.8	0.9	1.4	1.3	2.0	4.0	1.6
Avg.	1.5	1.2	1.6	1.8	1.7	1.3	2.8	0.8
TABLE B: Structure Borne Vibrations in Direction of Load								
1000	1.8	2.3	2.7	2.7	0.8	0.6	0.8	0.5
1800	0.8	1.7	4.6	2.3	1.0	0.8	0.9	0.2
2500	0.7	1.6	4.0	3.8	0.7	0.6	1.0	0.5
3600	0.6	0.8	2.9	2.8	1.0	0.8	2.3	3.0
Avg.	1.0	1.6	3.6	2.9	0.9	0.7	1.3	1.1
TABLE C: Airborne Noise (decibel difference) (negative difference indicates higher noise level of smaller bearing)								
1000	-	1.5	5.0	7.5	-	0.4	-6.0	-
1800	-	3.0	13.9	9.0	6.8	3.6	-1.5	-0.6
2500	-	3.0	13.5	7.0	1.5	-1.1	-2.7	-1.0
3600	-	4.6	5.2	1.6	1.7	-1.6	-1.4	-2.7
Avg.	-	3.0	9.4	6.3	2.5	0.3	-2.9	-1.1

Bearings Measured Without Radial Load (1800 rpm, Standard [illegible] Tester)

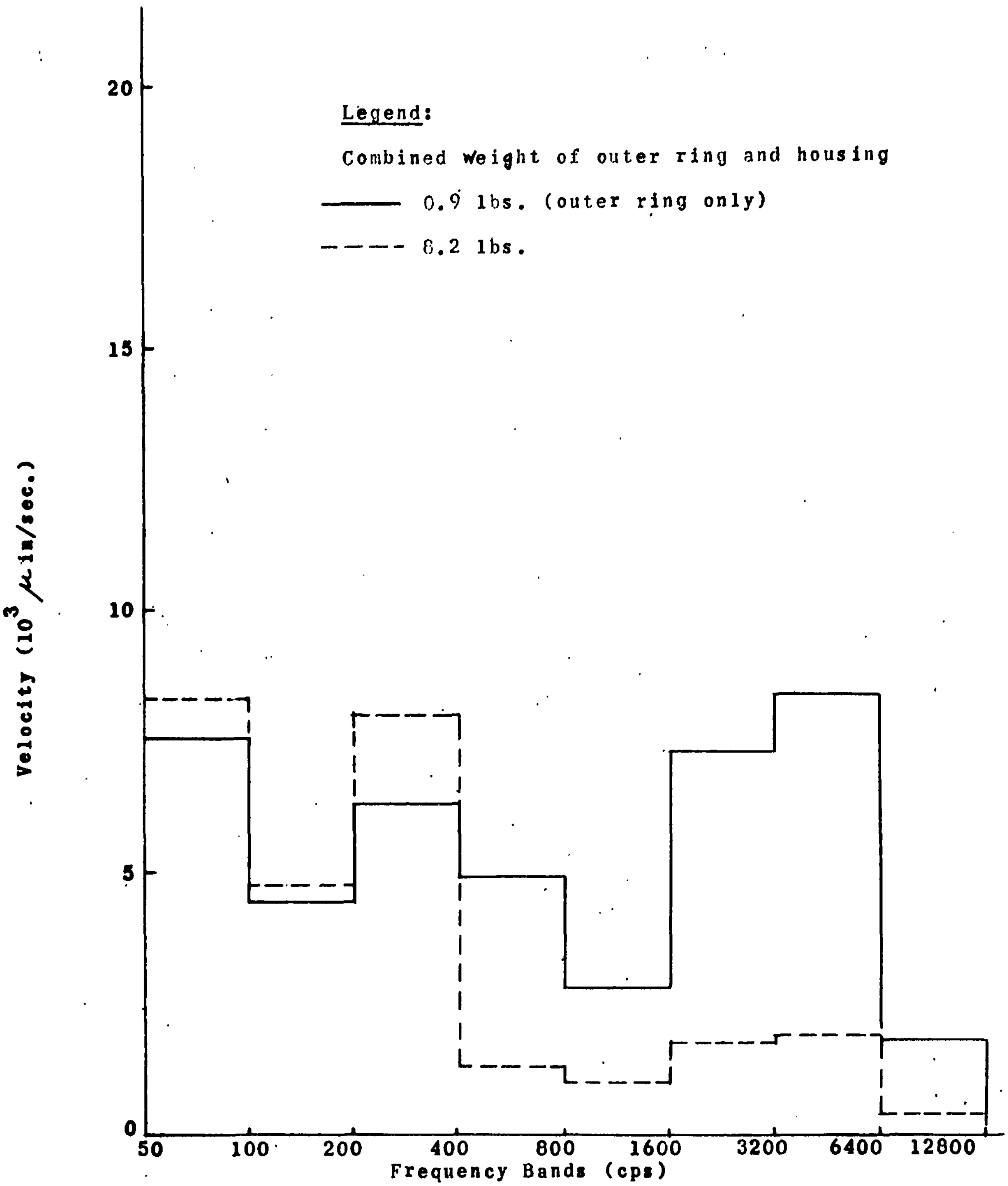
	50-100	100-200	200-400	400-800	800-1600	1600-3200	3200-6400	6400-12800 cps
TABLE D: 6310 Compared to 6305 (both without housing)	1.3	1.5	1.8	2.2	1.2	3.5	2.7	1.4
TABLE E: 6310 Compared to 6205 (both without housing)	1.1	0.9	1.3	1.3	1.2	4.5	4.7	1.7
TABLE F: 6310 Compared to 6205 (both with 8 lbs. housing)	0.9	0.8	1.1	1.0	2.2	5.8	9.4	8.0
TABLE G: 6310 (with 8.2 lbs.) to 6305 (with 1.5 lbs.)	0.5	1.6	2.5	0.3	0.8	2.0	3.1	1.1



ENCLOSURE 38 OCTAVE BAND ANALYSIS OF 6205 SIZE BEARING STRUCTURE BORNE VIBRATIONS WITH FOUR DIFFERENT MASSES (HOUSINGS) ON THE OUTER RING, MEASURED ON STANDARD E.B.E. SPINDLE (NO RADIAL LOAD, 6 lbs. AXIAL LOAD)



ENCLOSURE 39 OCTAVE BAND ANALYSIS OF 6305 SIZE BEARING STRUCTURE BORNE VIBRATIONS WITH AND WITHOUT HOUSING. MEASURED ON STANDARD SKF SPINDLE (NO RADIAL LOAD, 6 lbs. AXIAL LOAD)



ENCLOSURE 40 OCTAVE BAND ANALYSIS OF 6310 SIZE BEARING STRUCTURE BORNE VIBRATIONS WITH AND WITHOUT HOUSING MEASURED ON STANDARD [illegible] SPINDLE (NO RADIAL LOAD, 10 lbs. AXIAL LOAD)